Thos. N. Jenkins'

A STUDY OF THE RELATION OF ACCURACY TO SPEED

BY

HENRY E. GARRETT, Ph. D.

(Assistant in Psychology, Columbia)

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INTRODUCTION

The question of the relation of the speed or the quickness of a judgment, perception, or movement to its accuracy is one of no little importance. The desirability of accuracy has never been questioned; but speed is so variable and so individual a matter that it is rather difficult to think of a general relationship between the two factors. In fact, our daily experience reveals a good deal of variation in the time necessary for judgment under different conditions. There would, very probably, be considerable difference in both the character and the exactness of a judgment rendered after one second, and one given after one minute. Given a situation which remained essentially constant, and we should expect that if adaptation and fatigue were eliminated, the judgment or the perception would grow in accuracy with the increase in time taken to make it. The factors involved would gradually coalesce and in consequence, there would be an increase in the confidence with which the judgment was made. No doubt this is what actually does happen in many sensory judgments and perceptions. Oftentimes the perception of difference or similarity increases to a point of maximum clearness, beyond which a prolongation of time results only in doubt, or hesitations:—instead of the decision increasing in accuracy and certainty, the reverse is true, and inaccuracy and uncertainty arise. This suggests an optimal time for perception of difference, which varies with the individual, stimuli, and conditions. Incorrect judgments would then be those given before or after this optimal point had been reached.

In the case of movements, simple and complex, the problem, being more objective, is more easily investigated; though the

information here is still far from exact. Everyday knowledge seems to indicate that, in general, accuracy diminishes as speed increases, but there is little detailed information beyond the bare statement. We do not know, for example, except in certain cases[1] which have been studied, whether accuracy falls off regularly as the speed increases or whether there is a point at which accuracy is greater than at higher or lower rates; nor do we know how the increases in speed affect accuracy.

The experiments described in the following paper are concerned with certain aspects of the speed-accuracy relation; more exactly with this relation as it shows itself in the perception of small differences or in comparison of stimuli close together on the quantitative scale. In the present experiments, an attempt has been made to answer the following questions:—

1.—Will accuracy fall off regularly as speed increases, or is there an "optimal" point, as suggested, at which the accuracy is higher than at lower or higher rates?

2.—How do the increases in speed affect the accuracy, e.g. proportionally, or otherwise?

3.—Do speed and accuracy have essentially the same relation in the perception of differences, as in simple motor coordinations, or does the accuracy behave differently (with increases in speed) in the two cases?

4.—Does the same individual hold his position (relative) in the different situations,—is he fast and accurate, slow and accurate, etc., or can individuals be so classified?

As material for the experiments on the judgments of differences, I used lifted weights, lines, and specimens of handwriting. In the lifted weights and the handwriting, the stimuli were presented successively, the standard always preceding the variable stimulus; with the lines the stimuli were presented simultaneously. In every case the speed, the period of exposure or judgment or both, was the controlled factor and the accuracy was measured by the number of correct responses. For comparison with the results obtained from this group of experiments, two fairly simple tests of coordination were employed, in order to see whether the relationship of speed and accuracy found in the perception experiments also obtained in the field of movement.

[1]Woodworth—Accuracy of Voluntary Movement, PsM, 1899-1900, Vol. 3. XIII.

A brief resume of the studies made of the speed-accuracy relation precedes the experiments. In this review, the studies have been classified generally in the same order in which the experiments are given—weights, lines, writing, coordination. All relevant studies, however, no matter what the experimental material employed, have been included.

SECTION 1

HISTORICAL SURVEY

1. Lifted Weights

The object of the greater part of the experimental work done on Lifted Weights has been the testing of the validity of Weber's Law, the measurement of sensitivity, the analysis of the factors which enter into a sensory judgment, etc. The question of the relation of the time or rate of lift, or the time given for judgment, to the accuracy of discrimination has usually arisen incidentally as the result of a variation in procedure, or as an interesting sidelight on the main problem:—in no instance has it been the chief interest. I have, therefore, in citing results from the classical work done in this field, restricted myself to those references which are directly pertinent to the problem dealt with in this paper. For, as a matter of fact, to review, even briefly, the extensive literature which has grown up around the subject of Lifted Weights would be impossible in a limited space, and for the present purpose, it would be unnecessary.

In the year 1858, Fechner[2] in an experiment on lifted weights with himself as subject made 16,384 lifts using a stanadard of 1000 gms. and two comparison weights differing from the standard by 40 gms. and 80 gms. respectively. Four time intervals for lifting were used: ½″, 1″, 2″, 4″,—and the lifts were divided equally between the left and the right hands. In the 4″ interval, fatigue clearly entered as a factor; nevertheless, the accuracy of judgment varied but very slightly for all rates, apparently the only real effect of the long interval[3] being an increase in the time error: the tendency to overestimate the second weight. This caused Fechner to conclude that slow lifting results in the overestimation of the second weight. He states further[4] that large differences between weights are most easily perceived by rapid lifting, small differences by slow lifting. Fatigue[5] tends to increase the general acuity of perception; which phenomenon, Fechner explains as due

[2]Elemente der Psychophysik, Erster Theil, Leipzig, 1889, p. 305ff.
[3]Op. cit. p. 307.
[4]Revision, 364.
[5]Op. cit. 307-323.

to the more active circulation, as shown, for example, in the increased pulse rate. This increased flow of blood renders the brain more susceptible to fine differences, and results in a more acute sensitivity.

After Fechner, the most elaborate researches on lifted weights are those of G. E. Müller and his pupils Martin, Steffens, and Schumann.[6] These investigators were interested chiefly in the analysis and description of the psychological factors which enter into our judgments of lifted weights. One of their distinctive contributions is the idea of the motor "Einstellung," or "set" of the muscles for certain stimuli, eg. light or heavy weights. For example, a person who has been lifting weights in the order light-heavy for some time, on substituting a lighter weight for the heavy, will find that the 2nd weight seems much lighter than it actually is. This is explained as due to a persistence of set or adjustment of the muscles for the first weight combination, and the influence of this set on the second weight pair. The experiment of Steffens[7] supports this conception of the persistence of set. Motor set is also held to be one cause of constant errors, since weights lifted with great rapidity tend to be underestimated, and those lifted slowly overestimated.

In line with the motor factor is the discovery of Martin and Müller[8] of the dependence of judgment in the case of lifted weights on the "absolute impression" of the standard or variable weight, present to consciousness in tactual or kinaesthetic terms—rather than on the memory image or on an actual comparison of the two weights. Other more theoretical influences in determining judgment found by these authors are the "type tendency of judgment"[9] and the "general tendency of judgment"[10] that the percent of right cases is greater when the standard preceeds than when it follows the variable. The question of the "absolute impression," and the judgment

[6]Martin & Müller: Zur Analyse der Unterschiedsempfindlichkeit, Liepzig, 1899. Steffens, Laura: Über die motorische Einstellung,—Zeitschrift für Psychologie und Physiologie der Sinnersorgane, 1900, 23, 240-308. Müller & Schumann: Über die psychologischen Grundlagen der Vergleichung gehobener Gewichte, Archiv für die Gesamte Physiologie, 1899, *14*, 37-112.

[7]Op. cit. 274.

[8]Op. cit. 44ff.

[9]Op. cit. 29ff.

[10]Op. cit. 64ff.

tendency are considered at some length in the present experiment (p. 38). Martin and Müller[11] determined the time required for a judgment by counting the metronome beats without the subject's knowledge. They find that the discrimination of differences requires a shorter time than the recognition of equality, and that the greater the difference between the two weights the shorter the judgment time.

The fact that a weight seems lighter when lifted rapidly than when lifted slowly, lead Muller and Schumann[12] to conclude that the basis of judgment is the rapidity with which a weight is lifted. This is the Müller-Schumann Theory: a light weight is lifted higher and faster than a heavy weight and hence an O's decision depends on the ease with which a weight's inertia can be overcome.

Fullerton and Cattell[13] supplement a research on lifted weights with a series of experiments, in one of which (p. 131) the rate of movement was varied so that one weight was lifted four times as rapidly as the other "either by being lifted higher in the same time, or the same distance more quickly." The height of lift was, for weights one and two respectively, 16 cm. 4 cm., or 4 cm.-16 cm.; and in the experiment in which the time was varied, the time of lift was 2″-½″, or ½″-2″. Two weights, a standard of 100 gms. and a comparison of 108 gms. were used; and 200 experiments of each sort were made on two subjects. The failure of the PE's to change appreciably, cause Fullerton and Cattell to conclude (in contradiction to the theory of Müller and Schumann) that we do not judge differences in weights by the rate with which they are lifted; rather, the chief factors in the comparison they believe to be cutaneous sensations in the fingers against the weights, eg. to prevent them from slipping, and muscular sensations in the arm and fingers. Further confirmation of this fact, according to these authors, is to be found in the fact that we judge the force of a movement better than the time or the distance through which the movement is made.

The work of Jacobi[14] has a bearing on the general problem of the influence of the speed of the lift on accuracy. With the

[11]Op. cit. 196.

[12]See Zur Analyse der Unterschiedsempfindlichkeit, 207-208.

[13]On the Perception of Small Differences, 1892, 117-132.

[14]Untersuchungen über den Muskelsinn, Archiv. für Exp. Path. und Pharmakologie, 1893, *32*, 49-100.

object of seeing if the heavier of two weights requires more time to "get started" than the light, and whether this delay or inertia is not the factor that determines judgment, Jacobi used an apparatus which registered the moment at which the weights began to rise. He found that when the difference in time between the two weights was less than .08″ the weights were called equal; from .08″-.12″ the weights were often called equal; but when the difference in time was greater than .12″ the weights lifted more slowly was always judged the heavier. The conclusion drawn by Jacobi was that weights are compared and judged in terms of the time necessary to overcome their inertia. Jacobi states further that if we surmise in advance that one of two weights is the heavier, we lift it wth greater force, and if the two weights take about the same time in the lifting, we judge our surmise to have been correct.

The work of Jacobi, while suggestive, can not be accepted strictly at face value: Woodworth[15] in commenting on his results, remarks that his experiments were not numerous enough to establish a correlation between time and judgment. Claparede's work[16] on the size-weight illusion, seems to show that both inertia and height of lift are factors in the comparison of weights. Claparede used three cubes 512, 1728, 4096 cc. in volume respectively, each weighing 345 gms. Each weight was raised by a ring attached to its upper face, and an electric contact was made when lifting began. The height to which the weights were lifted was also recorded. On the average, it took .12″ to overcome the inertia of the largest weight, .21″ the medium weight, and .62″ the smallest weight. The largest weight was raised 25 mm., the medium 20 mm., and the smallest 10 mm. Since the illusion causes the largest weight to be judged the lightest, there is seen to be a correlation between the speed with which inertia is overcome, and the judgment of heavier or lighter: and also a correlation between the height to which weights are raised and judgment.

Kinnaman[17] finds the basis of judgment to be the "memory of a former change of sensation as compared with present

[15]Le Mouvement, Paris, 1903, 137.

[16]La Vitesse des soulevements lors des illusions de poids, L'Année Psychologique, 1901, *7*, 646-648.

[17]A Comparison of Judgments for Weights Lifted with the Hand and the Foot, Amer. Jour. Psy. 1900, *12*, 240-263.

changing sensation."[18] In lifting a weight there is probably a normal rate of change in sensation at which the total amount of change can be judged most accurately, varying with different observers. The speed, according to Kinnaman, may be either too rapid or too slow for taking these changes into consciousness, and in this way affect the judgment.

In some of the more recent work,—Urban,[19] Fernberger,[20] and Brown,[21] the relation of the time of judgment to accuracy has not been an object of study, and the rate of lift has been definitely regulated, or kept fairly constant throughout. Urban and Fernberger used a metronome set to beat at 92 times per minute, with bell marking the fourth beat. Four beats were given each weight, so that each lift occupied a little more than 2½″. In Brown's experiments, the speed and the height of lift, though left to the subject, were fairly constant; each lift occupied about ¾″, with an interval of ¼″, between lifts, and an interval of about 3¼″ between weight pairs. As Brown used only one subject it was fairly easy to keep the time relations standard.

2. Linear Magnitudes

In most of the experiments with linear magnitudes, the discrimination time for differences has been under the subject's control, and has not been arbitrarily varied as in the experiment described in this paper. In the method usually employed, the stimuli, eg. two lines differing in length, are exposed, the subject reacts to the longer or the shorter (according to instructions) by releasing the appropriate key, and the time of reaction is registered on a chronoscope. The accuracy is fixed, therefore, and the time of response is the measured factor in the present experiment, on the other hand, the TIME is fixed (or varied only by the experimenter) and the accuracy of perception difference is the measured factor.

In the following brief historical summary, I have attempted to review only those investigations which have a bearing on the general problem of the relation of time of perception to accuracy in the case of linear magnitudes. Only those results have been included which are relevant to the specific problem of the relation of Accuracy to Speed.

[18]Op. cit. 257.

[19]The Application of Stat. Methods to Problems of Psychophysics, 1908.

[20]On the Relation of the Methods of Just Perceptible Differences and Constant Stimuli, Psy. Rev. Monog., 1913. *14*, No. 61.

[21]The Judgment of Difference, Univ. of California Pub. 1910, Vol. 1.

One of the first experiments to bring out clearly the effect of the time factor on the perception of differences between linear magnitudes, is that of Münsterburg[22] in which the object was to test the psychophysic law, eg. "that equal subjective differences are correlated with equal objective relations of stimuli." Münsterburg used the chain method of reaction. One person reacted and gave stimulus to the second, the second to the third and so on until the last person gave the stimulus again to the first. The average time of discrimination was found by subtracting the reaction time of the first person from the total time elapsing between first stimulus and the last reaction and dividing the result by the number of subjects: in this case five. The stimuli, which were exposed in a rather complicated apparatus, were lines of 2.5-5-7.5, 4-5-6, 4.5-5-5.5 mm., respectively, with four multiples of each: making three main groups in all. A disc containing a line equal in length to the second line of each group was placed before the observer. Three fingers of the right hand rested on keys, which were pressed according to the stimulus exposed: the first, if the line exposed were shorter than the standard, the second if equal, and the third if longer. Münsterburg's results indicate that, in general, the psycho-physical law holds, eg. that it requires as long to discriminate between 5 and 2.5 mm., as between 10 and 5, or 15 and 7.5 mm. He notes, however, a "perfectly regular variation from the law" in that the difficulty of discrimination decreases slightly but regularly with increasing length of line. It requires for example, .1 sec. less to discriminate between 27 and 30 mm. (682 sigma) than between 4.5 and 5 mm. (792 sigma) lines one-sixth as long. Münsterburg qualifies his conclusion, therefore, by stating that "the stronger effect of the relative differences of stimuli is constantly influenced by the weaker effect of the absolute differences of the stimuli."

It is worth noting that Münsterburg worked throughout with lines, the differences between which were easily perceptible; and that the only direct bearing which his work has on the Speed-Accuracy relation is the discovery that once having found the time necessary for perceiving the difference between say, 20 and 30 mm. we should expect the time for accurate discrimination of 10 and 15 mm. to be equally as long.

[22]A Psychometric Investigation of the Psychophysic Law, Psy. Rev., 1894, *1*, 45-51.

In a series of earlier experiments, Münsterburg[23] examines the conditions which affect the perception of linear magnitudes, paying special attention to the part played by eye movements in visual judgments. The apparatus used was a wooden frame 600 mm. long and 500 mm. wide covered by a green cloth. Both vertical and horizontal lines were exposed on this screen at a distance of 600 mm. from the subject, with and without eye movements, simultaneously, successively, with varying intervals, etc. Both monocular and binocular vision were used and 20,000 experiments were made with 20 lengths, ranging from 10 mm. to 200 mm. in steps of 10 mm. The main results which are of interest to the present problem are given:

1.—Every change of eye movement, fixation or use of the eyes affects our estimations of lengths; muscular sensations or their after images are, therefore, necessary to explain errors.

2.—Distances to the left are usually overestimated, to the right underestimated, due probably to habits formed in reading and writing from left to right.

3.—Distances reproduced after varying intervals are usually overestimated. The variable error increases with increases of interval from 1″-10″.

4.—The variable line as compared with the standard is usually overestimated.

5.—In the estimation of simultaneously presented lengths when the eyes are free to move the AE varies between 1.1% and 2.3%; without eye movements the AE's vary from 3.7% to 4.9%. This is taken as proof of the dependence of our estimations of magnitudes on the intensity of muscular sensation.

Henmon[24] reports three groups of experiments on colors, lines and tones, by the "discrimination time method"[25] the object of which was to measure the difference in sensation by the time it takes to perceive them. Henmon divides his work on lines into two parts: one series of experiments dealing with absolute, and another with relative differences. The lines, which were 2 mm. wide and 10 mm. apart, were drawn with great care: two lines, a standard and a comparison to each card. In the first half of the work, six pairs of lines with

[23]Beiträge zur experimentellen Psychologie, 1889, 125-181.

[24]Time of Perception as a Measure of Differences in Sensation, Archiv. Phil. Psy. and Sc. Methods, 1906.

[25]Ladd & Woodworth, Physiological Psy., 1911, 360.

absolute differences of .5, 1, 1.5, 2, 2.5, 3mm. from a standard of 10 mm. were used; while the material for the second half consisted of standard lines of 5, 10, 15, 20 mm. and variables which differed by 20% from each standard line respectively. The lines were exposed in an exposure apparatus, exposure continuing until the subject reacted by releasing a key with the right or left hand, according as the stimulus to which he was to react appeared on the left or on the right. The time of discrimination was recorded by a Hipp chronoscope. The following conclusions are drawn from Henmon's work on lines.

1.—As the differences in length of lines decrease in arithmetical progression, differences in the time of perception increase in geometrical progression for the region tested.

2.—For equal relative differences the time of perception tends to remain constant, indicating the approximate validity of Weber's Law for the range used.

In his experiments on color, Henmon found that as the difference between a pair of Red and Red-Orange stimuli is lessened, the time of perception is increased, though the time differences are not proportional to the stimuli-differences. With tones varying in pitch by 4, 8, 12, 16 vib. the same general result was obtained: the time of perception increases as the differences between the stimuli decreases, (with considerable individual difference).

Henmon[26] describes a series of experiments with lines, the object of which was to find (1) the relation of the time of judgment to accuracy, (2) to study individual differences in judgment times. The specific problem was to discriminate between two lines, 20 and 20.3 mm. long, arranged horizontally on a card 10 mm. apart. The lines were exposed after the method employed in the previous experiment, exposure continuing until a judgment was made, with the subject reacting one-half the time to the longer, and one-half the time to the shorter line. Four degrees of confidence were recognized; a, perfectly sure, b, fairly sure, c, uncertain, and d, guess. There were three subjects, from each of whom 1000 reactions were taken. Henmon's observations are as follows:

1.—The average times of R-judgments are shorter than for wrong. Wrong judgments are absolutely and relatively more variable.

[26]Time and Accuracy of Judgment, Psy. Rev., 1911, *18*.

2.—Correct judgment of difference seems to grow to a point of maximum clearness; which suggests an optional time varying with the individual, stimulus, and conditions.

3.—There is a high correlation between confidence and accuracy.

4.—Introspection gives evidence that a prolongation of the judgment-time introduces an element of doubt.

5.—There is a uniform decrease in R-cases with decrease in confidence: also an uniform increase in time with decrease in confidence.

Hermon's subjects showed marked individual differences in accuracy, time of perception, and degree of confidence. Accuracy ranged from 68.6% to 83.2%; time of reaction from 304 sigma to 1095 sigma. The degrees of confidence have different values for different individuals, one subject giving "a" 90.4% of the time, and another only 9.3% of the time. Quick subjects were neither more nor less confident than slow. Henmon concludes that the relation of subjective confidence to accuracy is an individual matter.

Simpson[27] among other tests, used two on discrimination of linear magnitudes. In the first, the subject estimated the comparative length of pairs of horizontal lines: 108-100 mm., 106-100 mm., 104-100 mm., 102-100 mm., the lines drawn side by side one pair to a card. In the other test, the subject was required to draw lines equal to a given line, each line being covered as soon as made, so that the next would be an estimate of the standard line and not a copy of the line just drawn. Simpson found that the fast workers made the best records,—that little was gained by hesitation.

Peterson, G. S.[28] reports an experiment with linear magnitudes "undertaken to show the relation between time and amount of difference, time and accuracy, and between accuracy and the amount of difference in two ways: (1) By varying the size of the difference about any standard, (2) By varying the standard with the difference constant."

Peterson used twelve lines, in pairs, arranged about three standard lines 5, 10, 20 mm. long respectively. Each pair of lines consisted of a standard and a variable: four variables

[27]Correlation of Mental Abilities, Columbia Univ. Contributions to Education, Teachers College Series, 1912, *53*.

[28]On the Speed and Accuracy of Judgment of Horizontal Lines, M.A. Essay, Columbia University, 1916.

for each standard being used. The differences between the standard and the variable varied from .5 mm. to 3 mm. For the 5 mm. standard the variables were 5.5 mm., 6 mm., 7 mm., and 8 mm.; for the 10 mm. standard, 9.5, 9, 8, 6 mm.; for the 20 mm. standard 19.5, 19, 18, 16 mm. These lines were arranged one pair to a card, and were placed horizontally in the center of the card, separated by 1 cm. The cards were exposed in a tachistoscope, the subject reacting to the longer line as soon as the difference was perceived. Reaction time was registered on the Hipp chronoscope. On the basis of 4259 reactions taken from three subpects, Peterson concludes that (1) differences in perception time decrease approximately in GP as the difference between lines increase in AP; (2) error times are constantly less than correct times; (3) the more difficult the judgment, the more variable the perception time. Increase in difficulty leads to increase in time to be accurate, and results in fewer R-judgments; while decrease in difficulty leads to a decrease in time to be accurate and results in more R-judgments.

In addition to the results quoted from experiments with weights and lines, there have been several studies made of the speed-accuracy relation in experiments employing other material and apparatus. A brief account of these results will be given.

Angell and Harwood[29] and F. Angell[30] in an experiment with tone discrimination varied the interval between the first or standard tone and the comparison tone from 1″ to 60″. The comparison tone differed from the first by 0, ±4 or ±8 vibrations. There were four subjects and more than 6000 judgments were taken, with and without distraction during the interval between stimuli. Angell's results were as follows:

1. There is no loss in accuracy with increase in time interval up to 60″.
2. Distractions have little effect on the accuracy of judgment.
3. Introspections reveal a type of judgment termed "free": judgments delivered with considerable confidence, but without the presence in consciousness of any comparison of standard and variable.

[29]Experiments on Discrimination of Clangs for Different Intervals of Time, Part I, Amer. Jour. Psy. 1899-1900, *11*, 67-79.

[30]Part II, Amer. Jour. Ps. 1901, *12*, 58-79.

Angell F.[31] in a later series of three experiments, studied the influence of time interval on the accuracy of discrimination for different shades of grey. In the first experiment, a disc containing black and white in equal proportions was exposed for 2″ on a color mixer; and after a given interval,—5″, 15″, 30″, 60″—a comparison disc containing 200, 190, 170, 160, degrees of black was shown. Judgment of the comparison in terms of the standard were "darker," "lighter," or "same." The result of this experiment for two subjects indicated that "the accuracy of the judgment is practically independent of the time interval employed." This is true whether the subject makes an effort to "hold fast" to the visual image during interval, or merely remains relaxed with no definite attempt to fix the attention on the stimulus just seen. Two years later in a repetition of the same experiment with two subjects, under more carefully controlled conditions, Angell obtained the same result as to the influence of the time interval on accuracy. In another experiment of the same general sort, and with the same material, Angell measured to tenths of a second the time of the judgment for the four categories, "sure," "fairly sure," "like," i.e. same, and "doubtful." His results showed that "sure" judgments were the shortest, "like" judgments the longest. Angell notes again the presence of "free" judgments: —those in which no direct comparison of the standard and variable seemed to occur.

Whipple, G. M.[32] in an experiment on the discrimination of clangs and tones, varied the interval between stimuli from 2 to 60 sec. Whipple used an Appunn Tonometer; five tones were taken as standards, and the comparison tones differed from the standards by 0, +8, –8, vibrations. The relation of speed of judgment to certainty, and correctness; and the relation of speed of judgment to immediacy and correctness, were considered. It was found that (p. 445-6) immediate judgments were usually both certain and correct, while the delayed or compared judgments were more often uncertain and incorrect.

Bentley[33] in an elaborate study of memory fidelity for bright-

[31]Philos. Studien, 1902, *19*, 1-21.

[32]An Analytic Study of Memory Image and the Process of Judgment in the Discrimination of Clangs and Tones, Amer. Jour. Psy. 1901, *12*, 409-446.

[33]The Memory Image and its Qualitative Fidelity, Amer. Jour. Psy., 1899, *11*, 1-48.

nesses and colors, investigated in the course of his experiment the influence of the time interval between standard and comparison discs on the quality and fidelity of the memory image. Black, white, and colored discs, in various proportions were used as stimuli. Bentley's results showed no loss in accuracy of visual memory up to 6″, and a very slight loss up to 60″. After one minute there was a loss, increasing with the interval.

Woodworth[34] devotes one section of a research on the accuracy of voluntary movement to the relation between the speed of a movement and its accuracy. This last was tested out in two ways, by ruling lines on a drum, and by hitting at a target in various ways. In the first experiment, the requirement was that each line should equal the one immediately preceding it; in the other tests, the subject was required to thrust with a pencil alternately at three dots arranged in the form of an equilateral triangle, and 15 cm. apart respectively, or to hit with a pencil point at the center of each in turn of small squares in a sheet of coordinate paper. Speed was regulated by a metronome. Woodworth found that with increase in the speed of movement, there was a corresponding decrease in accuracy; but that movements at 40 per minute were as accurate as those at 20 per minute, while movements at 140, 160, 180, 200 per minute were all about equally as accurate—or inaccurate. Accuracy, then, did not vary proportionally or regularly with the increases in speed. The analysis of the factors entering into such movements as the ones here described, as well as the effect of variations in interval between movements, adjustment and control of the movement process, etc., have been considered at greater length in the experiment on Thrusting to the present paper. Woodworth suggests that there is an optimum interval between the movements studied, but this point cannot be located with any high degree of certainty as it varies with the right or left hand and the character of the movement.

Morgan, J. J. B.[35] reports an experiment on speed and accuracy of motor adjustments, the object of which was twofold; (1) to find the speed of adjustment to a change in load, (2) to find how accurately one can compensate for changes in

[34] Accuracy of Voluntary Movement, Psy. Rev., Mon. 1899, 27-54.

[35] The Speed and Accuracy of Motor Adjustments, Jour. Exp. Psy., 1917, *2*, 225-248.

load by changes in time so as to keep the physical force exerted the same throughout. Morgan's apparatus consisted of a movable carriage, to one end of which was attached a cord to be pulled by the subject; and at the other end, a cord which passed over a movable pulley to which weights were fastened. The carriage ran in grooves hollowed in horizontal guides; a 100 vib. tuning fork attached to it wrote during movement on a flat smoked surface underneath. Morgan found, in the first place, that a subject's idea of his maximum force is largely determined by the resistance to the movement involved; and that the quickness with which adjustment is made indicates that it is of the reflex type. In the second place, it was found that subjects do not possess the ability to adjust the force of a movement accurately, so that the same physical force will be exerted with different weights; in other words, the subjects judged of the force exerted by the time of pull, while they compensated for different loads (when told to exert the same force) by means of a very crude time correction.

Gould[36] in a study of transfer of practice in motor activity, used a test in which both speed and accuracy were required. The general scheme of the test was adapted from McDougall's "Dotting Test."[37] Sheets containing small circles irregularly arranged were fastened on a metal drum, which revolved on a horizontal axis. The subject's task was to hit the middle dot as the rows passed successively by a small window cut in a wooden screen placed before the drum. The drum was set to revolve at four speeds; so that one row of circles passed before the window in 2″, 1.6″, 1.2″, 1″ respectively. Two groups of boys were used as subjects; a group of 61 Prevocational school boys, and a "control" group of 62 academic boys. Both groups performed the experiment twice with the interval of a year between. Using the median score in the first test for the group of PV boys, the accuracy records for the four rates are 114, 115, 111, 105. The loss in accuracy when the speed is doubled is, then, 8%, while the accuracy remains at the same level for the first two rates. After a year, the scores for the same group are 116, 115, 111, 105; the speed, increased by 100%, resulting in a loss in accuracy of 9.5%. For the control group, in the first test the scores are 120, 113, 111, 105, a

[36]Transfer of Manual Accuracy in Prevocational School Boys, M.A. Essay, Columbia, 1917.

[37]Br. Jour. Psy. 1905, 435ff.

loss in accuracy of 12% as speed doubles. After a year the scores of the control group are 114, 111, 108, 107, a loss of about 6% in accuracy. The loss in accuracy was, therefore, not at all proportional to the increase in speed.

Studies in which tests of perception or discrimination, eg. cancellation tests, have been utilized, have a bearing on the problem of the speed accuracy relationship, because correlations have been found for speed and accuracy (in many cases), and because of the time corrections for errors and omissions. These corrections are for the purpose of converting speed and accuracy into one single coefficient.

Cattell and Farrand[38] in scoring the A-test, used with College Freshmen, made a "rough correction" for mistakes by adding to the total time the time that would be required to discriminate and mark the letter omitted or wrongly marked. Cattell and Farrand remark that subjects are slow and accurate, slow and inaccurate, fast and accurate, and fast and inaccurate:—no correlations were found.

Wissler[39] in his A-test with Columbia Freshmen, found a correlation between speed and accuracy of –.28.

Wyatt and Brown[40] in cancellation tests with school children mark +1 for each symbol correctly marked, and –1 for each mistake or omission.

Simpson[41] in the A-test, added 5″ for each A omitted to the total time. In the geometrical form test, he added 3″ to 6″ depending on the symbol omitted. The few errors due to wrong cancellation were neglected.

Whipple[42] reports a correlation for speed and accuracy of –.37, for 50 Grammar School boys, when one lettter was cancelled: and a correlation of -.64 for the same group when four letters were cancelled. With 30 University students, Whipple found a correlation of -.48 when four letters were cancelled.

Woodworth and Wells[43] suggest that in the number checking test, a correction should be made of 2% of the subject's total time as a penalty for each error or omission when one-half of

[38]Psy. Rev. 1896, 3, 641.

[39]The Correlation of Mental and Physical Tests, Psy. Rev. Mon. 1901, p. 20.

[40]Quantitative Investigation of Higher Mental Processes, Brit. Jour. Psy. 1913, *6*, 114.

[41]Op. cit.

[42]Manual of Mental and Physical Tests, Pt. 1, Simpler Processes, 1914, 318.

[43]Association Tests, Psy. Rev. Mon. 1911, *13*.

the blank is used; and a correction of 1% when the whole blank is used.

Strong[44] when using the Woodworth-Wells Number Checking Test, made a correction by finding the time for cancellation of a single symbol and adding twice this time to the recorded time.

Thorndike[45] reports an investigation on the relation of speed and accuracy in addition in which 671 students were used as subjects. The best 65 students averaged 15 additions per 100 sec., the worst 20 averaged 37 in the same time. The best group made 7 errors in 100 additions, the slow group 17½. Thorndike concludes that a person who is rapid will tend to be accurate also.

Bird, Grace E.[46] tested 100 College students with slow and rapid adding of examples taken from the Courtis Tests. The students added for two minutes as rapidly as possible; then for two minutes in which they were cautioned to work slowly and avoid errors. In the first test with the rapid addition, the median number of errors was 3, with a quartile deviation of .5; in the second test with the slow addition, the median number of errors was 4, with a quartile deviation of .8. When introspections were taken, all but three of the subjects mentioned distractions during the slow adding, while only five record any distraction during the rapid adding. The distractions mentioned include a variety of imagery, adding by combining units rather than groups, unnecessary repetition of sums obtained in the process of adding a column, emotional disturbances, physical uneasiness, shifting of attention to the environment, forgetfulness of sum already obtained, losing place, amusement at the experiment, etc. Bird attributes the superiority of the rapid addition to a difference of adjustment. In slow addition distractions come in, a reversion to childhood habits, eg. counting on the fingers, lip movements, vocalization etc.; in the rapid addition, irrelevant matters are crowded out through the inhibitory nature of the work, and the response becomes more automatic.

Due largely to differences in the "setting" of the experiments, methods and materials, it would seem to be rather

[44] A Comparison between Experimental Data and Clinical Results in Manic-Depressive Insanity, Amer. Jour. Psy. 1913, *24*, 83.

[45] Relation of Speed to Accuracy in Addition, Jour. Ed. Psy. 1914, *5*, 536.

[46] The Devious Path of Slow Work, Jour. Ed. Psy. 1922, *13*, 50.

difficult, or impossible, to gain any clear conception of the speed-accuracy relation, in general, from the above resume. It does appear, however, that the time given for perception or discrimination in those experiments, eg. lines, weights, tones, brightnesses, etc., in which differences are to be perceived, has little effect over a fairly wide range of time intervals; while in experiments dealing largely with cancellation the accuracy-speed relation is inverse. In movements requiring accurate and precise coordination, drawing lines, thrusting at dots, etc., the loss in accuracy is very small in comparison with the increases in rate, and in adding, both a motor and mental function, speed and accuracy are directly related. Practically nothing can be said in regard to an optimal interval for perception of difference, as little attention has been given this question; in simple movements, however, the evidence in favor of such an interval is fairly conclusive.

SECTION II.

1. Speed and Accuracy in Lifted Weights.

PROBLEM

In the experiment here described, the problem was to find to what extent the accuracy of weight discrimination is affected by the rate at which the weights are lifted, and the length of the interval between successive lifts. This question may well be resolved into two parts:—

(1) What effect does the rate of lifting have on the accuracy of judgment? and (2) What effect does the time-interval for judgment have on the accuracy of discrimination? In addition to these questions, further interesting corallaries grow out of the main problem. Some of these are noted. As the rate of lifting changes, what change will there be in the so-called threshold? Is the tendency to overestimate the second weight increased or diminished by the increase in the lifting rate? Is there an "optimal rate" at which accuracy is higher than at lower or higher rates? What is the relation between the confidence of the subject in the accuracy of his judgment, and the actual results obtained at the different rates? There arises, too, the question of individual differences in the course of the experiment, and, though it is realized that not much can be generalized about differences among individuals with only six subjects, still a comparison of results is suggestive, and in an experiment of this nature often brings out real differences.

APPARATUS AND PROCEDURE

The Method of Right and Wrong Cases in the simplified form advocated by Jastrow[47] and Fullerton and Cattell[48] was used. This method seemed preferable to the older and more complex form because accuracy percentages, thresholds, C E's etc., can, by means of it, be easily and quickly calculated. For other advantages and reasons for the elimination of the "equal" judgments, see Woodworth, Archiv. of Psy. 1914, No. 30, 65-68.

[47]Amer. Jour. Psy. 1887, *2*, 271-309.

[48]On the Perception of Small Differences, 1892, 119-120.

The weights used were cylindrical wooden boxes 4½ cm. high, and 6½ cm. in diameter. These boxes were loaded with paraffin and shot and were carefully weighed. There were 14 weights in all:—7 standard weights, and 7 comparison weights. The standard weights were all 100 gms.; the comparison weights formed a series from 88 gm. to 112 gm. in steps of 4 gms. The boxes were all varnished black and were indistinguishable in appearance.

The technique employed in lifting the weights was a modified form of Urban's[49] method. The weights were arranged in pairs at regular intervals along the circumference of a table with a revolving top. A screen with an aperture cut for the lifter's hand shut off the subject's view of the weights, which, by means of a turning table could be brought in succession directly under the subject's hand. In this way the space error was eliminated. Any error due to the time order was constant, as the standard was always lifted first. The use of comparison weights which extend below and above the standard would seem, however, to obviate the necessity of using more than one time order.

When the subject had lifted the second weight of any pair, he was required to say whether it was heavier or lighter than the standard just lifted, and to state his confidence in his decision. The letters *a*, *b*, and *c* were used as measures of subjective confidence, *a* meaning "sure" of the correctness of the decision, *b* "fairly sure," and *c* "uncertain" or doubtful.

One experiment consisted of five revolutions of the table:—that is to say, 5 judgments on each weight pair, or 35 judgments in all. Between experiments there was a rest interval of 3 min., during which the experimenter rearranged the weights. The five series of settings used for the comparison weights were as follows:

1.—104, 92, 108, 88, 96, 100, 112.
2.—96, 104, 108, 112, 92, 100, 88.
3.—112, 104, 96, 100, 92, 108, 88.
4.—88, 100, 108, 92, 104, 96, 112.
5.—112, 88, 92, 96, 100, 104, 108.

Since the rate of lifting and the time of judgment were the important factors in this experiment, all the lifting was regulated by a bell metronome. Five rates of lifting were

[49] Applications of Stat. Methods to Problems of Psychophysics, 1906, 1-18.

used, with the metronome set at 60, 96, 120, 160, 240. This last rate was obtained by removing the runner from the pendulum of the metronome. When the beats were then timed with a stop watch, there were approximately 4 to the second. Four beats of the metronome were given for each weight, with a four-beat interval for judgment between successive weight pairs. After some experimentation it was found to be easier to let the bell mark the first movement in the lifting process, i.e. that of grasping the weight. On the bell, therefore, the subject's hand grasped the weight, at the second beat raised it, at the third beat returned it to the table, and at the fourth beat came up again.

The different times for lifting with their judgment intervals are designated as rates 1, 2, 3, 4, 5. At Rate 1, with the metronome at 60, 4 seconds were given each weight with a 4-second interval between weight pairs; at Rate 2, metronome at 96, 2½ seconds were given each weight, with a 2½-second interval; at Rate 3, metronome at 120, 2 seconds were given each weight, with a 2-sec. interval; at Rate 4, metronome at 160, 1½ seconds were given each weight, with a 1½-sec. interval; and at Rate 5, metronome at 240, 1 sec. was given each weight, with a 1-sec. interval. It must be remembered that the number of seconds "given each weight" does not mean the number of seconds that the weight was actually lifted as the procedure described above makes clear: only one-half of the total time was used for lifting.

One variation in method must be noted: namely that judgments were required on the 100 gm. weight when employed as a comparison weight, with a 100 gm. weight as standard. Since "equal" judgments were excluded, the inclusion of a weight pair objectively equal, was, in a sense, a deception and is not strictly in accordance with the simplified form of the Method of Right and Wrong Cases. In fact Jastrow[50] warns against it. My object was, however, to find the proportion of "heavier" and "lighter" judgments on a comparison weight equal to the standard, and to see how this proportion changed as the rate of lifting increased: further than this the results were not used. The fact that the threshold for chance was below 100 gms. at all lifting rates, and that the 100-100 gm. pair were, therefore, not subjectively equal, offers some evi-

[50] "A Critique of Psychophysical Methods," Amer. Jour. Psy. 1888, *2*, p. 288.

dence in justification of the inclusion of the 100 gm. weight as a comparison.

Brief introspections were taken in the course of the experiment as to the criteria of judgment, feeling of confidence, ease with which the various rhythms could be followed; and any hesitation or apparent discomfort on the part of a subject at a given rate was noted by the experimenter, as none of the subjects were trained in careful or elaborate introspection, these records are used chiefly as a commentary on the objective results.

FATIGUE AND PRACTICE

In a series of experiments extending over a fairly long period of time, fatigue must be considered as a factor. Accordingly, in addition to a rest period of 3 minutes between each group of 35 lifts, i.e. 5 revolutions of the table, no series of experiments extended for longer than one hour, so that fatigue could hardly have been present to any appreciable degree. Then, too, the weights were relatively very light. Unfortunately, a definite time of day could not be set, and the experiments were made both morning and afternoon as the subjects were available.

"The consensus of opinion," according to Whipple[51] is "that, at least in comparison with many other mental activities, the discrimination of lifted weights is but little affected by practice." Spearman,[52] hovever, reports that his subjects have "invariably" shown improvement in the first fifteen minutes, and that a preliminary practice series is necessary if reliable records are desired. Fernberger[53] also finds considerable practice at the beginning of an experimental series. He insists that at least 50 determinations should be made on each weight, if a real measure of sensitivity is required; ten determinations are practically useless. To offset the practice factor, each subject in the present experiment was given a

[51]Manual of Mental and Physical Tests, I, 228.

[52]Gen. Intell. Objectively Determined and Measured, Amer. Jour. Psy. 1904, *15*, 233.

[53]The Effects of Practice in its Initial Stages in Lifted Weight Experiments and its bearing on Anthropometric Measurements, A. J. Ps., 1916, Vol. 27, 271.

series of preliminary lifts, to aid him in securing technique, as well as familiarity with the different rhythms. Furthermore, the experiments were taken in groups alternating from one rate to another, so that whatever practice there might be present would be spread over the whole experiment, and not be cumulative at any one rate. Records from the different rates can, therefore, be fairly compared.

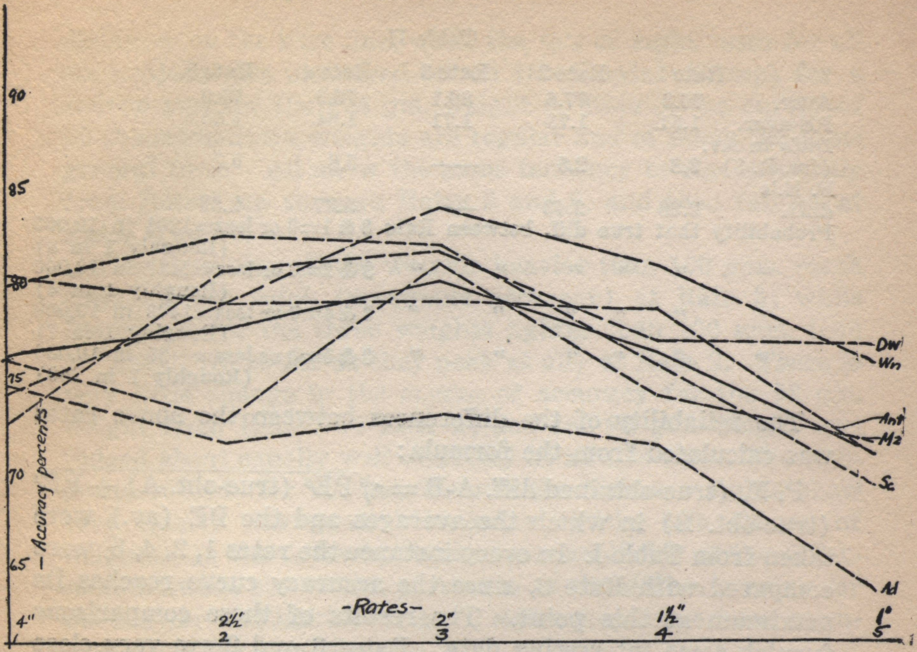
RESULTS

There were six men who acted as subjects in this experiment: Mz and Wn, both graduate students in psychology with some laboratory training, and Ad, Dw, Ant, and Sc, all Columbia College undergraduates with at least one year's work in psychology.

Table I, page 32, contains the results of the entire experiment. It is made up of 5 sections, each containing the results of 2100 lifts made by six subjects at a given lifting rate. Each section gives the number of right and wrong cases for each weight difference, the total number of right and wrong cases, the % of right cases, for each observer, and the % of right determinations for each weight. The total % of right cases for a given rate is also given; with the PE's of these %'s calculated from the formula: $\text{PE (tr-obt. Av.)} = \frac{\text{P E (dis.)}}{\sqrt{\text{N}}}$ These values (PE's) indicate how much—with the chances even—the obtained averages may be expected to differ from the true averages.

Diagram I represents, graphically, each observer's accuracy record, in % of right cases, for each of the 5 rates. The diagram is schematic; the rates are laid off at equal distances along the base line, and the accuracy records in %'s right are placed on the Y-axis. The heavy line is the composite accuracy record for all six observers throughout the 5 experiments.

This general accuracy curve, which, like the curves for the individual subjects is plotted from the data of Table I, shows a slight rise in accuracy as the rate of lifting increases from the data of Table I, shows a slight rise in accuracy as the rate of lifting increases from Rate 1 to Rate 3; then a decrease at Rate 4, and a further and more pronounced "drop" at Rate 5. The following table gives the reliability of these changes in accuracy:



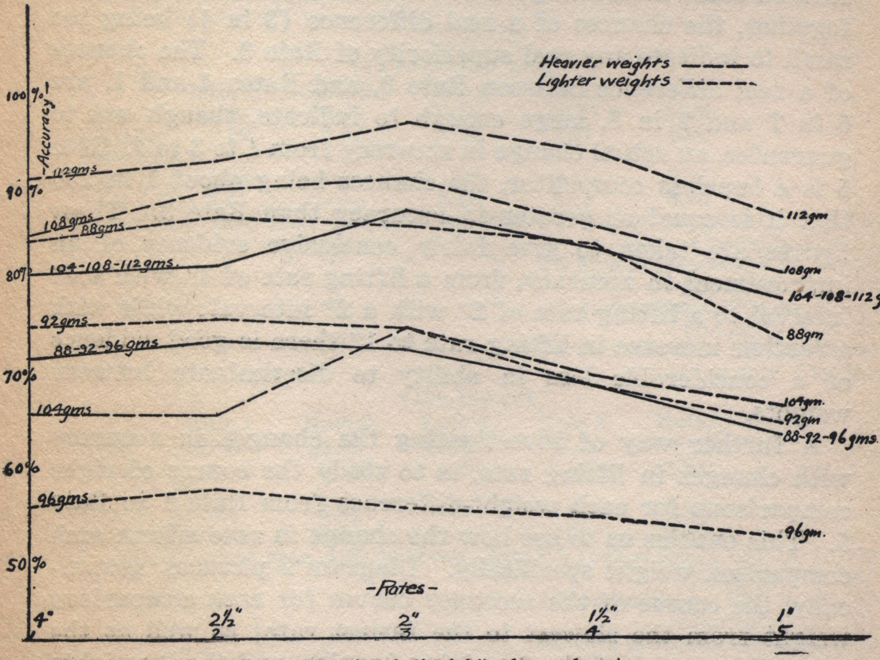


Diagram 1.—Accuracy records, (total % right), for each rate ————————
Individual records of 6 O's ....
Diagram 2.—Accuracy records, for heavier weights (104-108-112) and lighter weights (88-92-96).

Table II

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5
Aver.	76.3	77.6	80.1	76.3	70.9
PE-aver.	1.51	1.73	1.71	1.64	1.60
Diffs in Av. (fm. R. 3)	3.8	2.5	——	3.8	9.2
P. E.'s diffs.	2.28	2.43	——	2.37	2.29

Probability that true diff. between Rate 3 & 1=0 or less=1301 in 10,000 (Roughly 1 in 8)
" " " " " " 3 & 2=0 or less=2437 in 10,000 (Roughly 1 in 4)
" " " " " " 3 & 4=0 or less=1403 in 10,000 (Roughly 1 in 7)
" " " " " " 3 & 5=0 or less= 35 in 10,000 (Roughly 1 in 250)

The reliability of the differences between the above rates was calculated from the formula:

P. E. (true-obtained diff. A-B $= \sqrt{PE^2 \text{ (true-obt. A)} + PE^2}$ (true-obt. B) in which the averages and the PE (av.) were taken from Table I. In every instance the rates 1, 2, 4, 5, were compared with Rate 3, since the accuracy curve reaches its maximum at this point. The results of these comparisons furnish some interesting data. Rates 3 and 2 are very close together, the chances of a real difference (3 in 4) being too small to indicate any real superiority of Rate 3. The chances of a real difference between Rate 3, and Rates 4 and 1, are 6 in 7 and 7 in 8, large enough to indicate, though not to guarantee, an actual change in accuracy from 1 to 3 to 4. Rate 5 is a hopeless competitor, the chances being about 1 in 250 that it is equal or greater in accuracy than Rate 3. These figures are taken to give fairly conclusive evidence of an improvement in accuracy, from a lifting rate of 4″ with a 4″ interval to a lifting rate of 2″ with a 2″ interval; while with a further increase in lifting rate to 1″ there is good evidence of a considerable loss in ability to discriminate between weights.

A further way of investigating the changes in accuracy with changes in lifting rate, is to study the course of right comparisons for each weight-difference from Rate 1 to Rate 5. This enables us to see how the change in rate affects each comparison weight specifically. Diagram 2 pictures, graphically, the course of the accuracy curves for each comparison weight from the slowest to the fastest rate; as well as the composite record of the 3 weights heavier, and the 3 weights lighter, than the standard weight. The rates occupy equal

distances on the base line, while the %'s of right cases for all six subjects are measured off on the Y-axis. Except for a sudden rise for the 104 gm. weight at Rate 3, the curves of all the comparison weights are regular and of much the same general form. All show the same tendency to rise gradually from Rate 1 up through Rates 2 and 3, and then fall off at Rates 4 and 5.

The curves for all the weights heavier than 100 gms. reach their highest point (maximum accuracy) at Rate 3; while the curves for the three weights lighter than 100 gms. tend to "peak" (in so far as they peak at all) at Rate 2. There is very little change in the course of accuracy for the 92 gm. weight from Rate 1 to Rate 3; and the 96 gm. weight was judged about equally well or poorly at all five rates. The composite records for the heavier and the lighter weights show very clearly this general tendency of the two classes of weights. In the following table the reliabilities of the differences between the accuracy records at the different rates for the heavier and lighter weights, separately, have been calculated after the plan of Table II.

Table III

(88-92-96 gm. weights)

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5
Aver.	71.90	73.45	72.55	69.11	64.00
PE-aver.	2.08	2.62	2.24	2.31	2.08
Diffs in Av.					
(fm. R. 2)	1.55	——	.90	4.34	9.45
PE's (dif.)	3.35	——	3.45	3.49	3.35

Probability that true diff. between Rate 2 & 1=0 or less=3781 in 10,000 (Roughly 1 in 3)
" " " " " " 2 & 3=0 or less=4304 in 10,000 (Roughly 1 in 2)
" " " " " " 2 & 4=0 or less=1978 in 10,000 (Roughly 1 in 5)
" " " " " " 2 & 5=0 or less= 287 in 10,000 (Roughly 1 in 35)

(104-108-112)

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5
Aver.	80.67	81.80	87.67	83.44	78.11
PE-aver.	1.93	2.15	1.93	1.83	1.84
Diffs in Av.					
(fm. R. 3)	7.0	5.87	——	4.23	9.56
PE's (diff.)	2.73	2.89	——	2.66	2.67

Probability that true diff. between Rate 3 & 1=0 or less= 421 in 10,000 (Roughly 1 in 23)
" " " " " " 3 & 2=0 or less= 857 in 10,000 (Roughly 1 in 12)
" " " " " " 3 & 4=0 or less=1403 in 10,000 (Roughly 1 in 7)
" " " " " " 3 & 5=0 or less= 79 in 10,000 (Roughly 1 in 125)

TABLE I

Discrimination of Lifted Weights:—Method Of Right & Wrong Cases:—Six Subjects:—10,500 lifts:—2100 at each of Five Rates of Lifting, (The 100 gm. weight is not included in the totals)

Rate 1. 4" 2100 Lifts.

	88		92		96		100		104		108		112		Tot.		%
Sub.	R	W	R	W	R	W	+	—	R	W	R	W	R	W	R	W	R
Mz	36	14	41	9	27	23	23	27	35	15	39	11	50	0	228	72	76.0
Ad	42	8	32	18	29	21	28	22	33	17	42	8	46	4	224	76	74.7
Dw	42	8	38	12	30	20	23	27	29	21	40	10	39	11	218	82	72.7
Wn	43	7	36	14	25	25	30	20	32	18	45	5	42	8	223	77	74.3
Ant	43	7	35	15	28	22	32	18	39	11	48	2	48	2	241	59	80.3
Sc	47	3	43	7	30	20	24	26	30	20	42	8	47	3	239	61	80.0
Sum	253	47	225	75	169	131	160	140	198	102	256	44	272	28	1373	427	
%R	84.3		75.0		56.3		53.3		66.0		85.3		90.7		76.3		
AD	4.3		6.7		3.0				5.3		5.1		6.4		PE(Av)=1.51		

Rate 2. 2½" 2100 Lifts.

	88		92		96		100		104		108		112		Tot.		%
Sub.	R	W	R	W	R	W	+	—	R	W	R	W	R	W	R	W	R
Mz	42	8	30	20	25	25	34	16	34	16	48	2	39	11	218	82	72.7
Ad	41	9	32	18	33	17	34	16	27	23	39	11	43	7	215	85	71.7
Dw	47	3	45	5	38	12	19	31	30	20	39	11	43	7	242	58	80.7
Wn	45	5	36	14	21	29	32	18	38	12	47	3	50	0	237	63	79.0
Ant	42	8	36	14	23	27	36	14	37	13	49	1	50	0	237	63	79.0
Sc	43	7	48	2	34	16	27	23	33	17	46	4	44	6	248	52	82.7
Sum	260	40	227	73	174	126	182	118	199	101	268	32	269	31	1397	403	
%R	87.0		75.7		58.0		60.7		66.3		89.3		89.7		77.6		
AD	3.7		11.6		12.2				6.3		7.5		6.9		PE(Av.)=1.73		

Rate 3. 2" 2100 Lifts.

	88		92		96		100		104		108		112		Tot.		%
Sub.	R	W	R	W	R	W	+	—	R	W	R	W	R	W	R	W	R
Mz	41	9	38	12	24	26	36	14	43	7	47	3	50	0	243	57	81.0
Ad	36	14	38	12	33	17	21	29	31	19	37	13	44	6	219	81	73.0
Dw	49	1	39	11	28	22	28	22	34	16	45	5	50	0	245	55	81.7
Wn	44	6	36	14	31	19	34	16	43	7	48	2	50	0	252	48	84.0
Ant	43	7	33	17	23	27	33	17	38	12	50	0	50	0	237	63	79.0
Sc	45	5	42	8	30	20	25	25	35	15	46	4	48	2	246	54	82.0
Sum	258	42	226	74	169	131	177	123	224	76	273	27	292	8	1442	358	
%R	86.0		75.3		56.3		59.0		74.7		91.0		97.3		80.1		
AD	6.0		4.2		6.3		9.7		8.0		6.0		3.6		PE(Av.)=1.71		

Rate 4. 1½" 2100 Lifts.

Sub.	88 R	88 W	92 R	92 W	96 R	96 W	100 +	100 −	104 R	104 W	108 R	108 W	112 R	112 W	Tot. R	Tot. W	% R
Mz	39	11	34	16	28	22	34	16	32	18	43	7	46	4	222	78	74.0
Ad	39	11	29	21	29	21	39	11	32	18	38	12	47	3	214	86	71.3
Dw	41	9	37	13	34	16	26	24	34	16	41	9	44	6	231	69	77.0
Wn	44	6	41	9	25	25	31	19	37	13	47	3	49	1	243	57	81.0
Ant	46	4	28	22	25	25	38	12	41	9	47	3	49	1	236	64	78.7
Sc	42	8	37	13	24	26	25	25	34	16	42	8	48	2	227	73	75.7
Sum	251	49	206	94	165	135	193	107	210	90	258	42	283	17	1373	427	
%R	83.7		68.7		65.0		64.3		70.0		86.0		94.3		76.3		
AD	4.3		8.0		5.7		9.6		5.3		5.3		3.0		PE(Av.)=1.64		

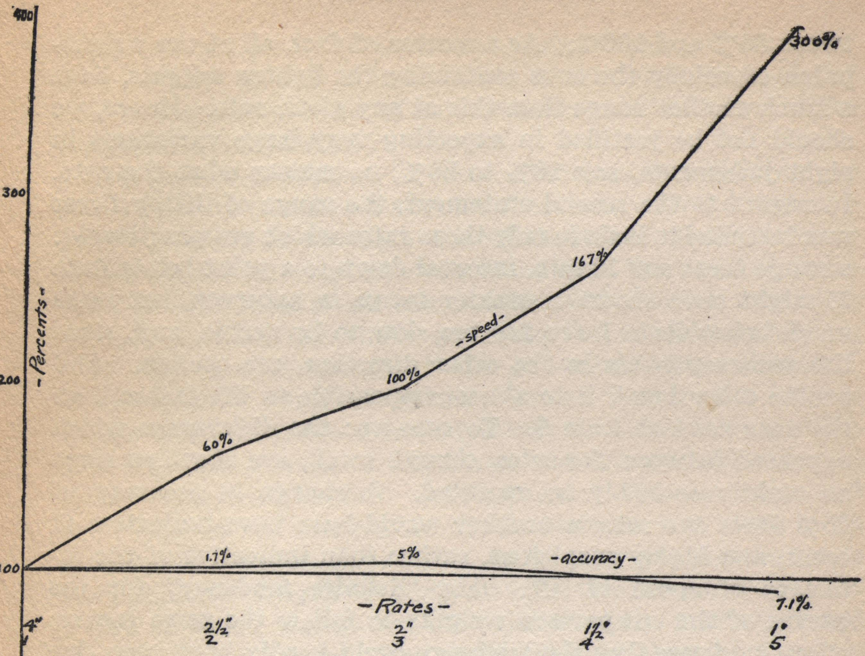
Rate 5. 1" 2100 Lifts.

Sub.	88 R	88 W	92 R	92 W	96 R	96 W	100 +	100 −	104 R	104 W	108 R	108 W	112 R	112 W	Tot. R	Tot. W	% R
Mz	37	13	35	15	29	21	35	15	28	22	43	7	42	8	214	86	71.3
Ad	29	21	28	22	25	25	36	14	32	18	36	14	40	10	190	110	63.3
Dw	45	5	42	8	34	16	23	27	24	26	39	11	46	4	230	70	76.7
Wn	40	10	36	14	29	21	25	25	37	13	41	9	44	6	227	73	75.7
Ant	33	17	25	25	23	27	38	12	39	11	42	8	45	5	207	93	69.0
Sc	34	16	29	21	20	30	35	15	40	10	41	9	44	6	208	92	69.3
Sum	218	82	195	105	160	140	192	108	200	100	242	58	261	39	1276	524	
%R	72.7		65.0		53.3		64.0		66.7		80.7		87.0		70.9		
AD	8.8		10.3		8.0		10.8		10.7		3.8		3.3		PE(Av.)=1.60		

The PE's of the differences show a pretty definite tendency for the accuracy record to reach its maximum point, in the case of the three weights heavier than 100 gms., at Rate 3, though the difference between this rate and Rate 4 is not very great—6 chances in 7. In the case of three weights lighter than the standard, there is not much evidence of a real change in the accuracy of discrimination from Rate 1 to Rate 4; such evidence as there is, is in favor of Rates 2 and 3. The decrease in accuracy at Rate 5 is, however, clearly present for both the heavier and the lighter weights.

In the diagrams up to the present, no account has been taken of the changes in the lifting rate which parallelled the changes in accuracy; the rates have been merely taken as equal lengths on the baseline. Accordingly, in Diagram 3, the corresponding changes in the two factors have been represented, measurement of both speed and accuracy being made from Rate 1 as 100%. With Rate 1 taken as 100%, Rate 2 becomes 101.7, Rate 3, 104.98, Rate 4, 100.0, and Rate 5, 92.90. It is clear that an increase in the lifting rate of 60%, at Rate 2, produced an increase of 1.7% in accuracy, while an increase of 100% in the rate of lift leads to an increase of 5% in accuracy. At Rate 4, with the speed increased 167%, the accuracy fell back to the level of Rate 1; and at Rate 5 an increase of 300% in lifting rate caused the accuracy to drop 7.1% below the accuracy level of Rate 1. This diagram, then, shows that while speed and accuracy in lifted weights are directly, though not proportionally, related up to a certain point, that when this point is passed the two variables are inversely related, increases in the rate of lift producing decreases in the accuracy record.

Before attempting to summarize the first part of the problem, the question of change in the accuracy of discrimination with change in lifting rate, it is well to consider two facts: (1) that the range of accuracy in the discrimination of weights is limited; and (2) that the difference between the slowest and the fastest rates is absolutely, though not relatively small. It must not be overlooked, also, that Diagram 2 shows a very definite tendency, mentioned before, for the curves of the comparison weights to follow the same course: a gradual rise and fall. In regard to the first statement: we should expect to get 50% of our comparisons right by chance, so that the extreme limits for accurate discrimination lie be-



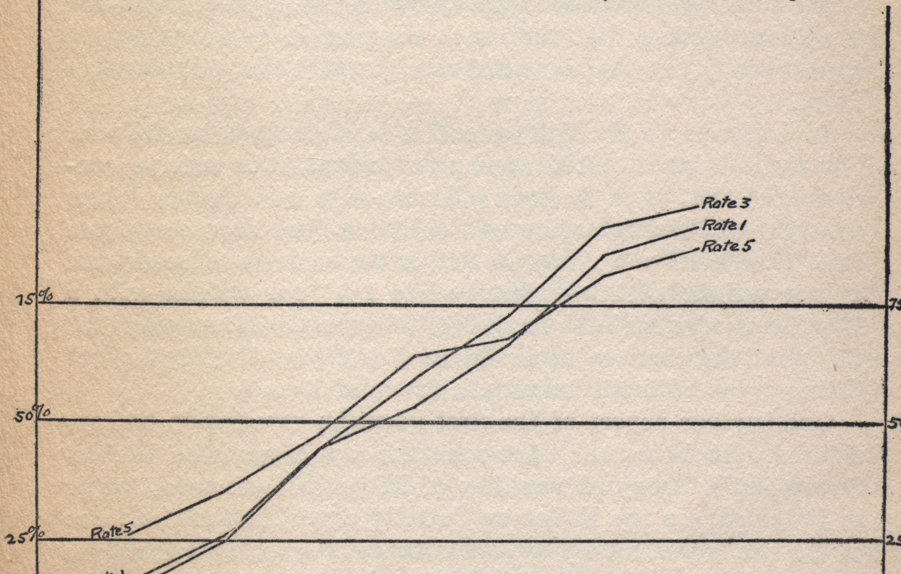


Diagram 3.—Showing the relative changes in accuracy with increased speed. Both speed and accuracy at Rate 1 taken as 100. Accuracy curve is combined records of 6 O's and represents 2100 lifts at each rate.

Diagram 4.—Showing the course of the "heavier" judgments for Rates 1, 3, and 5, for each comparison weight.

tween 50% and 100%. As a matter of fact, all of the weight-pairs, especially the ones containing the lighter weights, have a much smaller range than this at any given rate. Hence, we should not be justified in expecting very large variations in right judgments, say 10% to 90%, no matter what the rate. In regard to the second statement, the range of lifting times was intended to include only those rates which are practicable: a range from say 10 min. interval down to a point below Rate 5, might have shown a greater range in accuracy, but rates much below Rate 1 are far too slow to be usable, and, since the accuracy tends in the other direction, are useless. And on the other hand, it is almost impossible to lift faster than the rate used at Rate 5. To sum up: the differences which appeared between the rates, though small, are about as large as could reasonably be expected. A change in accuracy of 25% from one rate to another would have been indicative of error, and highly suspicious, rather than indicative of the influence of speed of lift. The "definite tendency" for the curves of the comparison weights to follow the same course, offers evidence that the tendency could hardly have been due to chance factors; but that such changes in accuracy as did appear are due to the increased rate at which the weights were lifted.

The answer to the first question is, therefore, as follows. For weights around 100 gms. as standard, it is safe to conclude (1) that there is good evidence of a real change in the accuracy of discrimination as the lifting time decreases from Rate 1 to Rate 5; (2) that the lifting time can be reduced from 4″ per weight with a 4″ interval to 1½″ per weight with a 1½″ interval with little or no loss in accuracy of comparison; (3) that the chances favor Rates 2 and 3 as the "optimum" lifting rates with the balance in favor of Rate 3.

One further aspect of the first question remains to be considered. It is agreed that whether we accept the Müller-Schumann[54] theory of rapidity of lift as the essential factor in judgment, or the Fullerton-Cattell[55] conception of the force of the lift, eg. in muscular and cutaneous sensations from the hand and fingers, as the chief determinant, that accurate discrimination certainly depends on the correct placing, on a

[54]Uber die psych. Grundlagen der Vergleichung gehobenen Gewichte, Archiv. fur d. ges. Physiol. 1889, *45*, 37ff.

[55]On the Perception of Small Differences, 1892, 132.

subjective scale of values, of the impressions got from the first and the second stimuli. How is this evaluation made? And how are we to think of an "optimum rate" in terms of the judgment consciousness?

The judgment process, in those situations in which we are called upon to compare a present sensation with one immediately preceding it, has been a much discussed question. Many of the earlier investigators[56] assumed that the basis of judgment in such cases is the comparison of the visual, muscular, tactual, or other sensations got from the second impression, with the memory image of the preceding one. Bentley,[57] however, in a study of memory image fidelity for brightnesses and colors, reported judgments in which introspection failed to find a trace of comparison of the two stimuli. In these "free judgments," decision came like a flash, and confidence in the correctness of the decision was often quite strong, even though the subject could not state how he made the judgment. Angell[58] reports an experiment with clangs, the object of which was to test the validity of the memory-image theory of comparison. His results showed that for time intervals from 1″ to 60″, there was but little falling off in the accuracy of judgment with increase in time for stimuli differing from 8 to 4 vibrations. Distractions, eg. addition, counting metronome beats, reading backwards, or aloud, applied during the interval did not affect the accuracy of judgment. Angell concludes that for the most part no comparison of standard and variable took place. Whipple[59] in a study of clangs and tones in which the interval between the first and the second stimuli was varied from 2 to 60 sec. also reports immediate judgments in which there was apparently no image present. Pillsbury[60] says "it has been noticed repeatedly that in comparisons, the first standard impression is not ordinarily in mind when the comparison results."

The most careful study of this problem as regards weight lifting has been made by Martin and Müller.[61] These authors

[56]Bentley: The Memory Image and its Qualitative Fidelity, A. J. Psy. 1899, *40*, 8.

[57]Op. cit., p. 39-40.

[58]Discrim. of Clangs for Different Intervals of Time, Amer. J. Psy., 1900, *11*, 58-79.

[59]An Analytic Study of Memory Image, and the Process of Judgment in Discrimination of Clangs and Tones, A. J. Psy., 1901, *12*, 409-457.

[60]Attention, 1908, 173.

[61]Zur Analyse der Unterschiedsempfindlichkeit, 1899, p. 43-44.

state, on the basis of a long research, that what actually takes place in weight comparisons, is that, in a long series the subject forms an "absolute impression" of the stimuli, more often of the variable than the standard. The weights are then judged heavier or lighter in terms of this Absolute Impression, of heaviness or lightness just as we speak of a clear day or a loud noise without comparison with any previous day or noise. Hayden,[62] in later work with lifted weights, accepts this conception of "set" or adjustment in the presence of which the second stimulus is received. Hayden emphasizes the verbal image as the impulse to the adjustment; through such an image, the standard weight is evaluated,—placed on a scale of values.

One further study should be noted. Fernberger,[63] using the Method of Constant Stimuli, has made probably the most careful introspective study of the factors present in judgments of comparing. Fernberger used weights, lines, sounds, and brightnesses. His subjects were required to give a careful description of everything which appeared in consciousness during the process of comparing; to state, as far as possible, on what factors judgment depended and how decision was reached. Fernberger concludes that "the structural components of the process of comparing, we found to be primarily sensations and images." The pattern of the comparing process differed with materials presented, individuals, and the stage of practice reached. Two main stages in the comparison of weights were distinguished. In the early stages, it is essentially the comparison of the imaginal representation of the first stimulus with a perception of the second stimulus. This "imaginal representation" consists of images of different modalities; always, however, there were kinaesthetic images present. In the second stage, a "set" or adjustment is recognized in the presence of which the comparison stimulus is evaluated. It is interesting to see how Fernberger reconciles the Martin and Müller-Fullerton and Cattell controversy on the basis of these two stages of practice. Fullerton and Cattell's subjects, he holds, being relatively untrained, remained largely in the first stage of practice; motor set was absent, therefore, or, if present, only to a slight degree.

[62] Memory for Lifted Weights, A. J. Psy., 1906, *17*, 497-521.

[63] An Introspective Analysis of the Process of Comparing, Psy. Monogr. 1919, *26*, 6.

Judgments were based, then, on kinaesthetic and tactual images of the first stimulus compared with the sensations arising from the second stimulus; that is to say, on the force necessary to hold the weights. Martin and Müller's subjects, being trained, were in the second stage of practice where motor set is the rule; judgments, under these conditions, are determined by the speed and height of lift. Fernberger believes that Fullerton and Cattell were justified in claiming that Müller's contention that judgments are based on the speed and height of lift, are not always true. It is untrue only for the early stages of practice, however.

The introspections of the subjects in the present experiment should be considered in this connection. As none of the subjects were particularly trained in introspection, their reports are rather meager, and are suggestive rather than conclusive. In calling for introspections each subject was asked specifically to state on what criteria his judgments were based, which rate seemed most "comfortable," how confident he felt in his judgments at the different rates, etc. This was done in order to secure definite information; suggestions, as far as possible, were avoided.

INTROSPECTIONS

Mz.—My judgments were based, I think, on muscle and touch sensations from wrist, forearm, and fingers. I had no images. Rate 1 seemed slow compared to the other rates, and I had difficulty in holding my attention to the task. Rates 2 and 3 were better, and I felt surer of myself. I was hurried at Rates 4 and 5, and rather uncomfortable.

Ad.—I found it easier to give a judgment at the slower rates; guessed some at Rate 4 and more at Rate 5. I believe that the slow lifting rate at Rate 1, and the long interval, really served as a distraction rather than as an aid. Often I found my mind "wandering" and my attention on something else. My judgments seemed based on hand and wrist sensations; often they were mechanical.

Dw.—I am not very sure how I compared the weights: muscle and touch sensations from the arm and the hand, I suppose. I preferred the faster rates. Rate 1 was too "dragging," and Rate 5 too strenuous to follow. I felt about the same degree of confidence throughout, except at Rate 5.

Wn.—I think that my comparisons were based on the pres-

sure necessary to hold the weight as I lifted it. Wrist and arm sensations probably came in also. I preferred Rates 2 and 3, and felt more confident there. Rate 1 was too monotonous, and Rate 5 too fast.

Ant.—I can't say exactly how I compared the weights. I think that sensations from wrist and fingers were the basis of judgment. I preferred Rate 2. I felt fairly confident at the first four rates, but very little so at Rate 5.

Sc.—I tried to compare the muscle sensations from the second weight with those from the first. I preferred Rates 2 and 3. Rate 1 was pretty slow, especially after the other rates, and it was hard to keep the attention fixed. I felt more confident at the first three rates.

The bulk of the evidence on the question seems to make it clear that, in the discrimination of lifted weights, a memory image is not usually present, but that, in time, the one impression creates a definite set or adjustment in terms of which the other impression is evaluated. The "optimal rate" is then explicable in terms of duration of memory or set. When the second weight follows the first too quickly, there is a confusion of the factors involved in judgment, i.e. the "psychic factors" of Martin and Müller;[64] when the second weight follows the first too tardily, there is a loss of set, a lapse of attention, and, introspection shows, the introduction of irrelevant factors. Commenting on the influence of the time factor in such judgments, Fullerton and Cattell[65] say:—

"In making experiments on the perception of Small Differences, the time elapsing between the sensations to be compared should not be neglected. In the experiments hitherto described (weights and lights) the interval was always one second. It is possible that two seconds or longer might be a more favorable interval for comparison, but were the interval further lengthened, the first sensation might be expected to fade from memory." Kinnaman[66] also writes: "Judgments of weights are based on focal and marginal sensations, which change greatly as the scale of weights is ascended. It is precisely this change of sensations occurring from the beginning of the lift until the weight clears the support, that we compare and

[64]Op. cit. p. 197.

[65]Op. cit. p. 147.

[66]A Comparison of Judgments for Weights Lifted with the Hand and Foot, A. J. Psy. 1900, *12*, 256-263.

TABLE IV

Discrimination of Lifted Weights when Lifting Time and Interval are varied independently:—2100 Lifts at each Rate:—6 Observers. (100 gm weight not included in totals)

Rate 6 — 1½" for lifting each weight—3" interval between weight pairs. 2100 Lifts.

Sub.	88 R	88 W	92 R	92 W	96 R	96 W	100 +	100 —	104 R	104 W	108 R	108 W	112 R	112 W	Tot. R	Tot. W	% R
Mz.	44	6	34	16	30	20	28	22	28	22	36	14	46	4	218	82	72.7
Ad	40	10	33	17	33	17	34	16	29	21	39	11	41	9	215	85	71.7
Dw	42	8	38	12	28	22	30	20	34	16	42	8	42	8	226	74	75.3
Wn	42	8	39	11	38	12	30	20	33	17	41	9	44	6	237	63	79.0
Ant	36	14	34	16	30	20	34	16	40	10	45	5	46	4	231	69	77.0
Sc	44	6	36	14	34	16	28	22	30	20	38	12	44	6	226	74	75.3
Sum	248	52	214	86	193	107	184	106	194	106	241	59	263	37	1353	447	
%R	82.7		71.3		64.3		61.3		64.7		80.3		87.7		75.17		
AD	4.4		4.0		5.7		4.3		6.7		5.0		3.0		PE(Av)=1.20		

Rate 7 — 3" for lifting each weight—1½" interval between pairs. 2100 Lifts.

Sub.	88 R	88 W	92 R	92 W	96 R	96 W	100 +	100 —	104 R	104 W	108 R	108 W	112 R	112 W	Tot. R	Tot. W	% R
Mz	42	8	36	14	25	25	32	18	35	15	40	10	44	6	222	78	74.0
Ad	41	9	32	18	28	22	28	22	32	18	40	10	43	7	216	84	72.0
Dw	46	4	42	8	32	18	32	18	38	12	42	8	40	10	240	60	80.0
Wn	34	16	34	16	30	20	32	18	40	10	46	4	46	4	230	70	76.6
Ant	42	8	36	14	28	22	30	20	39	11	47	3	47	3	239	61	79.7
Sc	44	6	35	15	34	16	25	25	38	12	45	5	46	4	242	58	80.7
Sum	249	51	215	85	177	123	179	121	222	78	260	40	266	34	1389	411	
%R	83.0		71.7		59.0		59.7		74.0		86.7		88.7		77.17		
AD	5.3		4.3		4.7		4.7		4.7		5.3		4.0		PE (Av) = 1.32		

judge, rather than the totality of sensation after the weight is up. The reagent will judge best when the speed and other conditions are most favorable for his taking these changes into full consciousness. If the normal speed is maintained, the height of lift is of little consequence provided the observer holds firmly to the changes which occurred at the beginning of the lift. But when the observer defers judgment, he is liable to question his impressions, and do little more than guess."

The second part of the problem has not yet been considered: namely, the influence of the interval between weight pairs on the accuracy of discrimination. This question has been investigated in a second experiment, the results of which are incorporated in Table IV. The results of the previous experiments have indicated a "fall off" in accuracy at Rate 4 for all the comparison weights, and it is important to know whether this loss is due to the increased lifting rate, to the shortening of the interval between weight pairs, or possibly to both factors. In the first experiment of Table IV, 1½″ were given for lifting each weight as in R-4, but the interval was increased to 3″—doubled. For simplicity, I have called this Rate 6. In the second experiment of Table IV, the lifting time was increased to 3″ for each weight, and the interval decreased to 1½″. This combination I have called Rate 7. In the following table, I have compared the reliability of the differences between the accuracy records for Rates 4 and 6, 2 and 7, and 6 and 7.

Table V

	Rate 6	Rate 4	Rate 7	Rate 2
Aver	75.17	76.30	77.17	77.60
PE-Av.	1.20	1.64	1.32	1.73
Diff. Rate 7 & 6			2.00	
Diff. Rate 4 & 6)		1.13		
Diff. Rate 2 & 7)				.43
PE-diff. Rate 7 & 6)			1.78	
PE-diff. Rate 4 & 6)		2.03		
PE-diff. Rate 2 & 7)				2.18

Probability that true diff. between Rates 7 & 6=0 or less=2210 in 10,000 (Roughly 1 in 5)
" " " " " " 4 & 6=0 or less=3528 in 10,000 (Roughly 1 in 3)
" " " " " " 2 & 7=0 or less=4464 in 10,000 (Roughly 1 in 2)

The comparison of Rates 4 and 6 shows the difference between the two rates to be very slight—practically negligible. With a difference in average of 1.13 and a PE (diff.) of 2.03, the chances of a real difference are about 2 in 3 in favor of Rate 4. Evidently the lengthened interval did not produce greater accuracy. When Rate 2 is compared with Rate 7, the chances are even of a true difference; here again the decrease in interval from 2½″ to 1½″ with approximately the same lifting rate, does not affect the accuracy of discrimination. When Rates 7 and 6 are compared, the chances are seen to be about 4 in 5 that Rate 7 is better than Rate 6. As between the two factors, therefore, of time of lift and interval between weight pairs, the evidence is in favor of time of lift as being much more important an influence in accurate discrimination than the interval. In fact, the interval seems to have little or no effect on accuracy.

In all the previous experiments no matter what the rate or the interval the experimenter had noticed that the observers nearly always gave their judgments immediately on lifting the second weight. After the experiment just described, the subjects were asked for an opinion on the influence of the interval. Their introspections bear out the results already given above: all were agreed that, except in a very few cases, their decisions were made as soon as the second weight was lifted, and that the interval had no influence unless very long or very short. In the very long interval it was hard to keep the attention from wandering, while in the very short one, i.e.—one second, there was hardly time to give the verbal response "heavier, a," or "lighter, c," on one weight pair before another pair appeared. Apparently the interval is not a judgment interval at all, but is nothing more than a necessary interim between successive weight pairs.

Several minor questions which arise from the main experiment remain to be considered. One of these is the question of the threshold. Table VI shows the changes in the "general threshold" at the different rates,—the threshold being taken as that difference which the observer can be expected to distinguish 75 times in 100. The entries in the table have been calculated from the Fullerton and Cattell[67] table, and measure directly the accuracy of discrimination. The records of the heavier and the lighter weights have been combined and the

[67]Op. cita p. 16.

Table VI

Threshold (75%) Values for Six Subjects at each of 5 Rates:—2100 Lifts at each rate: 10,500 total.

Rate 1

Obs	96 104	92 108	88 112	Av.	Ad.
Mz.	8.6	6.4	5.6	6.9	1.2
Ad.	9.0	8.0	6.7	7.9	.8
Dw.	11.8	7.0	9.2	9.3	1.6
Wn.	15.1	5.8	7.8	9.6	3.7
Ant.	5.9	4.7	5.7	5.4	.5
Sc.	10.5	5.2	5.2	7.0	2.4
Av.	10.2	6.2	6.7	7.7	1.7
Ad.	2.3	1.0	1.2	1.3	

Rate 2

Obs	96 104	92 108	88 112	Av.	Ad.
Mz.	11.4	5.4	9.2	8.7	2.2
Ad.	10.5	9.5	8.1	9.4	.8
Dw.	5.6	5.2	6.2	5.7	.4
Wn.	11.8	5.0	4.5	7.1	3.1
Ant.	10.6	4.1	4.0	6.2	2.9
Sc.	6.1	3.4	7.2	5.6	1.4
Av.	9.3	5.5	6.5	7.1	1.8
Ad.	2.4	1.4	1.6	1.3	

Rate 3

Obs	96 104	92 108	88 112	Av.	Ad.
Mz.	6.1	4.8	5.0	5.3	.5
Ad.	7.5	8.0	9.2	8.2	.6
Dw.	9.0	5.3	3.7	6.0	2.0
Wn.	3.9	4.6	4.6	4.4	.3
Ant.	9.8	3.9	4.8	6.2	2.4
Sc.	6.9	4.5	5.3	5.6	0.9
Av.	7.2	5.2	5.4	6.0	1.1
Ad.	1.6	1.6	1.2	0.9	

Rate 4

Obs	96 104	92 108	88 112	Av.	Ad.
Mz.	10.5	7.0	7.4	8.3	1.5
Ad.	9.5	12.0	6.9	9.4	2.6
Dw.	5.8	7.0	7.8	6.9	.7
Wn.	8.3	4.3	5.0	5.9	1.6
Ant.	6.0	6.3	4.7	5.7	.6
Sc.	13.3	6.7	5.9	8.6	3.1
Av.	8.9	7.2	6.3	7.5	1.7
Ad.	2.2	1.6	1.1	1.3	

Rate 5

Obs	96 104	92 108	88 112	Av.	Ad.
Mz.	15.4	6.7	10.0	10.0	2.9
Ad.	15.4	14.8	15.1	15.1	.2
Dw.	13.3	6.1	6.0	8.5	3.2
Wn.	6.3	7.3	8.0	7.2	.6
Ant.	9.0	12.3	10.5	10.6	1.1
Sc.	10.6	9.6	10.0	10.1	.4
Av.	11.7	9.5	10.0	10.1	1.4
Ad.	3.0	2.8	2.0	1.8	

Table VII

Constant Errors (Time) for Six Subjects at each of 5 Rates:—2100 Lifts at each rate:—10,500 total.

Rate 1

Obs.	96 104	92 108	88 112	Av.
Mz.	2.6	–.7	7.2	3.0
Ad.	1.3	3.8	2.0	2.4
Dw.	–.5	.7	–1.5	–.4
Wn.	3.9	3.2	–.5	2.2
Ant.	2.8	4.3	2.8	3.3
Sc.	.0	–.4	.0	–.1
Av.	1.7	1.8	1.7	1.7

Rate 2

Obs.	96 104	92 108	88 112	Av.
Mz	3.8	6.0	–1.6	2.7
Ad	–2.4	3.0	1.0	.5
Dw	–1.8	–2.0	–2.0	–2.0
Wn	8.1	3.6	3.5	5.1
Ant	5.8	2.4	4.0	4.1
Sc	–.2	–.9	–.5	–.2
Av.	2.2	2.0	0.9	1.7

Rate 3

Obs.	96 104	92 108	88 112	Av.
Mz	5.1	3.0	5.2	4.4
Ad	–.6	–.4	4.0	1.0
Dw	2.2	2.0	.7	1.6
Wn	2.3	4.0	3.9	3.4
Ant	4.4	5.7	4.4	4.8
Sc	1.4	1.4	1.9	1.6
Av	2.5	2.6	3.4	2.8

Rate 4

Obs.	96 104	92 108	88 112	Av.
Mz	1.6	3.2	3.5	2.8
Ad	1.2	4.6	4.1	3.3
Dw	.0	1.4	1.5	1.0
Wn	5.0	2.1	3.3	4.3
Ant	4.1	6.6	2.3	4.3
Sc	5.0	1.7	3.4	3.4
Av	2.8	3.3	3.0	3.1

Rate 5

Obs.	96 104	92 108	88 112	Av.
Mz	–.6	2.7	2.6	1.6
Ad	4.0	4.7	7.5	5.4
Dw	–4.1	–1.0	.5	–1.5
Wn	2.1	1.8	2.0	2.0
Ant	5.8	9.1	6.8	7.2
Sc	8.7	5.2	5.2	6.4
Av	2.7	3.8	4.1	3.5

PE's computed for a given weight difference irrespective of its direction from the standard. There is very little fluctuation in the averages calculated from the weight differences, except for the 4 gm. difference. Here the introduction of the

chance records of the 96 gm. weight is probably the cause, as the Fullerton and Cattell table does not give accurate results for %'s close to 50%. The threshold values for the 5 rates follow the general trend of accuracy, being lowest at Rate 3 and highest at Rate 5. The threshold value at Rate 3, 6, gms., is comparable to that got by Fullerton and Cattell, eg. 6.2 gms., in a series of 4000 lifts with 9 subjects.

The constant errors for each rate are given in Table VII. These values have been calculated according to the method given by Sanford.[69] The averages of the averages shows a tendency, usually found in lifted weight experiments, for the observers to overestimate the second weight. This tendency is evident at all rates and increases fairly regularly as the difference between the weights becomes larger; it is also present in increasing amounts from Rate 1 to Rate 5. With the space error ruled out by the arrangement of the revolving table, we may be inclined to attribute this error to the time factor since the standard always preceded the variable. It is doubtful whether this is more than partly true, however, because in spite of the single time order, S-V, in one-half of the lifts the comparison weight was heavier, and in one-half of the lifts lighter than the standard. Fechner attributed the time error to fatigue, especially with heavy weights, but this explanation is hardly admissible in this experiment. It may very well be that among other factors involved, (particularly with light weights) the tendency of judgment to take a positive form played a part. Hollingworth[70] in studying with 15 different modalities the tendencies and forms of judgment which were preferred when the observer "was left free to select both the direction of judgment (as to first or second stimulus) and the form of expression (positive or negative quality)" reports a "strong tendency to direct the judgment toward the stimulus described as 'positive' in quality" and a "slight tendency to favor the second stimulus presented." It might be, therefore, that as the rate of lifting increased and judgment approximated more closely the "snap" type, the observer if doubtful or "pushed for time" (the direction of judgment being fixed) would tend to say "heavier" rather than "lighter." The increasing number of heavier judgments on the

[68]Op. cita. p. 122.
[69]Experimental Psychology, 1908, p355-356.
[70]Experimental Studies in Judgment, Archiv. Psy., No. 29. p. 67

100-100 gm. pair, as the rate increased, offers some evidence in favor of this view.

In order to show that the rate of lift is a real factor in determining the accuracy of discrimination, and that the changes in accuracy are not due to the influence of the plus time error alone, I have plotted in Diagram 4 the course of the heavier judgments on each weight for Rates 1, 3, and 5. If the increase in the tendency to overestimate with more rapid lift were the only factor, the curve for Rate 3 should lie above the curve for Rate 1 throughout its course, and Rate 5 above Rate 3: i.e. the plus judgments should increase both for the heavier and the lighter weights. This is not true, however, as the curve for Rate 3 lies below Rate 1 for the lighter weights, and Rate 5 lies below Rate 1 for the heavier weights. The tendency to overestimate alone would have placed Rate 5 above Rates 1 and 3 for the heavier weights and Rate 3 above Rate 1 for the lighter weights. One point further. The tendency to overestimate the second weight and the fact that the point of subjective equality is really nearer the 98 gm. weight than the 100 gm. standard, give the heavier weights an advantage over the lighter ones in that they are actually further from the standard, and hence more easily discriminated. Accordingly, in the following table a comparison is made of the rates, in which the weight differences are taken from 98 gm. as the point of subjective equality, and 112 gm. weight is not

TABLE VIII

Degrees of Confidence for Varying Amounts of Weight Difference at each rate: Six Subjects:—5 Rates:—10,500 Lifts

Rate 1 4″

	88		92		96		104		108		112		Totals	
Obs.	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c
Mz	36	14	39	11	44	6	38	12	37	13	45	5	239	61
Ad.	28	22	30	20	31	19	38	12	38	12	43	7	208	92
Dw.	49	1	45	5	45	5	50	0	47	3	50	0	286	14
Wn.	29	21	23	27	23	27	32	18	30	20	35	15	172	128
Ant.	25	25	19	31	10	40	28	22	43	7	42	8	167	133
Sc.	22	28	21	19	9	41	13	37	23	27	23	27	111	189
Aver.	32	18	29	21	27	23	33	17	36	14	40	10	199	101
Weights	88		92		96		104		108		112			
%R-Cases	84.3		75		56.3		66		85.3		90.7			
%a&b	64		58		54		66		72		80			

Rate 2 2½″

	88		92		96		104		108		112		Totals	
Obs.	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c
Mz.	50	0	49	1	49	1	50	0	49	1	50	0	297	3
Ad.	36	14	31	19	28	22	39	11	35	15	47	3	216	84
Dw.	50	0	50	0	50	0	50	0	50	0	50	0	300	0
Wn.	30	20	23	27	12	38	20	30	36	14	38	12	159	141
Ant.	16	34	21	29	20	30	24	26	47	3	47	3	175	125
Sc.	14	36	9	41	3	47	12	38	35	15	32	18	105	195
Aver.	33	17	30	20	27	23	33	17	42	8	44	6	209	91
Weights	88		92		96		104		108		112			
%R-Cases	87		75.5		58		66.3		89.3		89.7			
%a&b	66		60		54		66		84		88			

TABLE VIII continued

Rate 3 2″

	88		92		96		104		108		112		Totals	
Obs.	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a& b	c
Mz.	48	2	50	0	50	0	49	1	50	0	50	0	297	3
Ad.	34	16	31	29	32	18	34	16	43	7	44	6	208	92
Dw.	50	0	50	0	50	0	50	0	50	0	50	0	300	0
Wn.	27	23	28	22	27	23	27	23	36	14	46	4	191	109
Ant.	30	20	18	32	26	24	38	12	47	3	49	1	208	92
Sc.	10	40	16	34	4	46	8	42	27	23	20	30	85	215
Aver.	33	17	32	18	32	18	34	16	42	8	43	7	215	85
Weights	88		92		96		104		108		112			
%R-Cases	86		75.3		56.3		74.7		91		97.3			
%a&b	66		64		64		68		84		86			

Rate4 1½″

	88		92		96		104		108		112		Totals	
Obs.	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a& b	c
Mz.	50	0	50	0	50	0	50	0	50	0	50	0	300	0
Ad.	39	11	40	10	46	4	41	9	46	6	48	2	258	42
Dw.	50	0	50	0	50	0	50	0	50	0	50	0	300	0
Wn.	36	14	28	28	26	24	26	24	48	2	45	5	203	97
Ant.	18	32	22	28	16	34	22	28	45	4	47	3	170	130
Sc.	11	39	5	45	3	47	11	39	23	27	24	26	77	223
Aver.	34	16	32	18	32	18	33	17	43	7	44	6	218	82
Weights	88		92		96		104		108		112			
%R-Cases	83.7		68.7		55		70		86		94.3			
%a&b	68		64		64		66		86		88			

Rate 5. 1″

	88		92		96		104		108		112		Totals	
Obs.	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a&b	c	a& b	c
Mz.	49	1	49	1	49	1	50	0	50	0	50	0	297	3
Ad.	32	18	38	12	42	8	40	10	35	15	43	7	230	70
Dw.	50	0	50	0	50	0	50	0	50	0	50	0	300	0
Wn.	32	18	20	30	24	26	28	22	37	18	39	11	280	120
Ant.	29	21	26	24	22	28	44	6	44	6	48	2	213	87
Sc.	4	46	1	49	2	48	4	46	25	25	29	21	65	235
Aver.	33	17	30	20	32	18	36	14	40	10	43	7	214	86
Weights	88		92		96		104		108		112			
%R-Cases	72.7		65		53.3		66.7		80.7		87			
%a&b	66		60		64		72		80		86			

	Weights 88-108	Weights 92-104	Weights 96-100
Rate 1	84.8	70.5	54.8
" 2	88.0	71.0	59.3
" 3	88.5	75.0	57.7
" 4	84.8	69.3	59.7
" 5	76.7	65.8	58.7

included. This comparison offers more evidence of a real change in accuracy with increased rate apart from the time error.

There is still an appreciable increase in accuracy from Rate 1, when the effect of the time error is, at least, partly eliminated. On the influence of the time error in general, it might be noted that Table VII shows that the increase in constant error from Rate 3 to Rate 5 is very small—.7; that the lighter weights do not decrease in accuracy from Rate 1 to 3 as they should if increased rate were effective only by increasing the time error; that the further increases at Rates 4 and 5 cause

losses in accuracy which are as large for the heavy weights as for the light weights.

Throughout the course of the experiments, the subjects were required to state their confidence in the accuracy of their comparisons by means of the terms a, b, c. This plan of recording a subject's confidence really combines the Method of Just Noticeable Differences with the Method of R. and W. Cases (vide Fullerton and Cattell, Small Differences, p. 124) on the supposition that a subject's confidence will tend to decrease as the differences between the objective stimuli decrease. Table VIII shows the distribution of a's, b's, and c's for each weight difference at each rate: and a comparison is made of the %R cases for each weight and the % of a's and b's for that rate. Though there is little change in the confidence as the rate increases (in spite of delayed or general introspections to the contrary) the degree of confidence is seen to increase pretty regularly with the % of R-cases, and with the increase in the weight interval. This result is substantial-

TABLE IX

Relation of Correctness of Judgment to Degree of Confidence: Six Subjects=5 Rates–10, 500 Lifts.

	MZ	AD	DW	WN	ANT	SC	AV
Rate 1							
a	85	87	86	90	90	100	89
b	72	62	81	75	87	82	76
c	60	68	52	61	63	62	61
Rate 2							
a	88	89	81	82	93	—	87
b	56	60	—	88	80	95	76
c	40	59	—	70	68	77	61
Rate 3							
a	95	86	82	100	95	—	91
b	76	70	—	83	83	98	82
c	75	63	—	74	59	66	66
Rate 4							
a	83	83	77	94	91	—	86
b	50	57	—	78	63	90	68
c	63	67	—	74	63	71	68
Rate 5							
a	79	70	76	94	82	—	80
b	53	57	—	83	87	95	65
c	—	60	—	60	57	62	60

Example:—For Mz at Rate 1, 85% of his "a" judgments were correct, 72% of his "b" judgments were correct, and 60% of his "c" judgments were correct.

ly that got by Williamson[71] in a study of the relation between an individual's degrees of confidence and objective differences in the stimuli compared. Williamson had 35 students arrange 25 statements or beliefs by both the Order of Merit Method and the Method of Paired Comparisons. The degree of confidence in the comparisons made by the latter method were required, confidence ranging from 0 to 3 in steps of 1. "0" meant "mere guess" and "3" "absolutely certain." The average confidences for every Rank Difference or "differences discriminated" as found by the Paired Comparisons Method were then correlated with the rank differences by the "squared difference" formula. For the 35 observers the coefficient of correlation ranged from +.705 to +.961 with a median of +.879.

Table IX shows how often the observers were right when *a*, *b*, or *c* was given. They seem to be, on the whole, fairly good judges of the accuracy of their comparisons, as they were more liable to be right when "sure" than when "doubtful." It is evident, too, that an observer is more apt to be right than wrong when he guesses or is doubtful (see Fullerton and Cattell, op. cit. 132).

It is also apparent that those men who were most confident were not always the most accurate:—Mz and Dw who gave practically all "a's." The observers differed much in their understanding of the terms *a*, *b*, and *c*. Dw, for example, was nearly always "sure," while Sc was nearly always "doubtful." Again, Wn and Dw, both of whom gave their judgments quickly and without hesitation were generally better at the faster rates; while Ad, and Ant, who were slow and cautious —inclined to be deliberate—were better at the slower rates, and drop regularly after Rate 3. Williamson[72] also found marked indvidual differences in the range of the correlation coefficients mentioned above, "conservative" persons tending to put a much greater distance between the limits set for confidence degrees, than the more "radical." Martin and Müller[73] classify observers in three groups or types: positive, negative, and indifferent. Those who belong to the "positive" group are strong and muscular individuals, who give a larger % of R cases when the standard is greater than the Variable. Those

[71]Individual Differences in Belief, Measured and Expressed by Degrees of Confidence, Jr. of Phil. Psy. & Scien. Method, 1915, 12, 127-137.

[72]Op. cit. 136-137.

who belong to the "negative" type are relatively weaker and non-muscular and give a larger % of R cases when the standard is lighter than the Variable. (In Martin and Müller's work, the standard came first.) Müller calls this tendency the "type tendency of judgment." In his experiments there were 5 men and 1 woman in the "positive" group, and 5 women and 1 man (of slight muscular development) in the "negative" group. According to this classification, the five observers in this experiment, being all men, should belong to the "positive" group, though the results indicate a larger % of right judgments when the heavier weights came second at each of the rates. This discrepancy in results, may be due to the fact that (1) Martin and Müller's weights were much heavier than the weights used in this experiment, ranging from 416-3,221 gms. and (2) that fatigue and actual muscular effort were absent or negligible among my observers. In general, I believe that the subjects in this experiment may best be classified as (1) impulsive, best at the faster rates, (2) cautious,—best at the slower rates, and (3) indifferent.

CONCLUSIONS

The following conclusions are drawn from this experiment:

1.—There is a real change in the accuracy of discrimination for Lifted Weights as the rate changes from a 4″ lift for each weight, with a 4″ interval between weight pairs, to a 1″ lift for each weight, with a 1″ interval between weight pairs. The Optimal Rate is close to 2″ for each weight with a 2″ interval between weight pairs.

2.—The time-interval (ostensibly given for judgment) is of little or no influence on the accuracy of discrimination, unless it is very long or very short: under both of which conditions it makes for inaccuracy.

3.—The 75% threshold is lowest at Rate 3.

4.—The tendency to overestimate the second weight increases regularly with increase in lifting rate.

5.—Confidence in the accuracy of judgment varies directly with accuracy of discrimination, but does not change much with increase in lifting rate. Different observers are, in general, quick, cautious, or intermediate in giving their decisions.

[n]Op. cit. p. 29ff.

2. Speed and Accuracy in Judging the Comparative Length of Lines.

PROBLEM

In this experiment an attempt was made to find what effect the time given for perception has on the accuracy with which lines of variable length can be judged longer or shorter than a given standard line. In each instance two lines were presented simultaneously, a variable and a standard; the speed, i.e. the interval of exposure, was varied in a regular and predetermined manner, and the accuracy was gauged by the correctness with which the variable line was perceived to be of different length from the standard. The record of the judgments at the different exposure intervals shows whether accuracy for lines tends to increase or diminish with decrease in exposure interval, and indicates, further, which exposure interval is productive of the greatest discriminative clearness. It is of interest to note the relative accuracy with which lines longer or shorter than the standard line are discriminated, and to see, also, how the observer's confidence in his estimates changed with the time allowed for decision. All these questions are considered under the results.

APPARATUS AND PROCEDURE

The exposure material consisted of 12 cards of white cardboard, 14″ by 6″ in size. In the center of each card a horizontal line was drawn, from the left end of which facing the observer a length of 100 mm. was cut off by an upright vertical line 5 mm. long and 2 mm. wide. This 100 mm. length served as the standard line for each card, while the remainder of the line (to the right of the vertical upright) varied in length from 95 mm. to 105 mm. and served as a comparison line to be judged longer or shorter in terms of the standard line. Each card, therefore, contained two lines a variable and a standard. These lines were all of uniform thickness, 1 mm. and, to insure accuracy, were drawn in India ink by an expert draughtsman. The exposure cards, which were rather large, were taken so purposely, in order to prevent judgments being given in terms of the distance of the end of the variable from the edge of the card, rather than the length of the variable itself.

The comparison lines were 95, 97, 98, 98.5, 99, 99.5, 100.5, 101, 101.5, 102, 103, 105 mms. respectively: six longer and six shorter than the standard. These lines were selected because they seem to give a fairly wide range, from differences which can be pretty clearly perceived, to those which do not yield much more than 50% of right determinations.

Different investigators have given different values to the j.n.d. for lines.

E. H. Weber puts the fraction by which one line must differ from another in order to be just perceived, as 1/100 of the standard line for people of keen eyesight. Weber used lines of 50 and 100 mm. as standards. For untrained observers, Weber puts the fraction at 1/25 to 1/20. Fechner reported correct judgments on lines which differ by 1/60 of the length of the standard; and Volkmann differences of 1/90 and 1/100. For a concise survey of these investigations, and of others made by the use of the various psychophysical methods primarily for the purpose of determining the ability of the eye to estimate linear magnitudes, see reference below.[74]

In comparing results got from different experiments with lines, the method of drawing and presenting the lines must be considered, as it makes a good deal of difference whether the lines to be compared are separately drawn, are parallel, or (as in this experiment) are parts of the same line. In the latter case, the judgment is clearly influenced by the presence of the whole line.[75]

For an exposure apparatus, I used a box 14½″ wide, 10″ long, and 6″ high. This box was open at the top and one side, and was large enough for the exposure cards to fit into it easily. The observer was seated about 10 feet before the open end of the box, and on a level with it, his back to a window. Care was taken to secure uniform lighting and to avoid shadows being cast across the face of the cards. Each card was numbered, and a tab fastened to the top so that it could be turned easily by the experimenter. The cards were exposed for a definite time interval, during which interval the observer designated the comparison line as longer or shorter than the standard; and expressed his confidence in

[74]Henmon: Time of Perception as a Measure of Difference in Sensation, Archiv. of Phil. Psy. & Scient. Methods, 1906, p. 54-61.

[75]Münsterburg: Beiträge zur experimentellen Psychologie, 1899, Heft 2,130.

his perception by the letters "a" sure, "b" fairly sure, and "c" uncertain or guess. The method is thus seen to be the same as that used in the previous experiments on lifted weights; Right and Wrong cases, plus the additional requirement that the observer give his feeling of confidence in his answer.

The twelve cards were presented in 20 successive series, the order of presentation being changed each time: thus at a given exposure rate an observer made 20 judgments on each line, or a total of 240 judgments on the 12 lines.

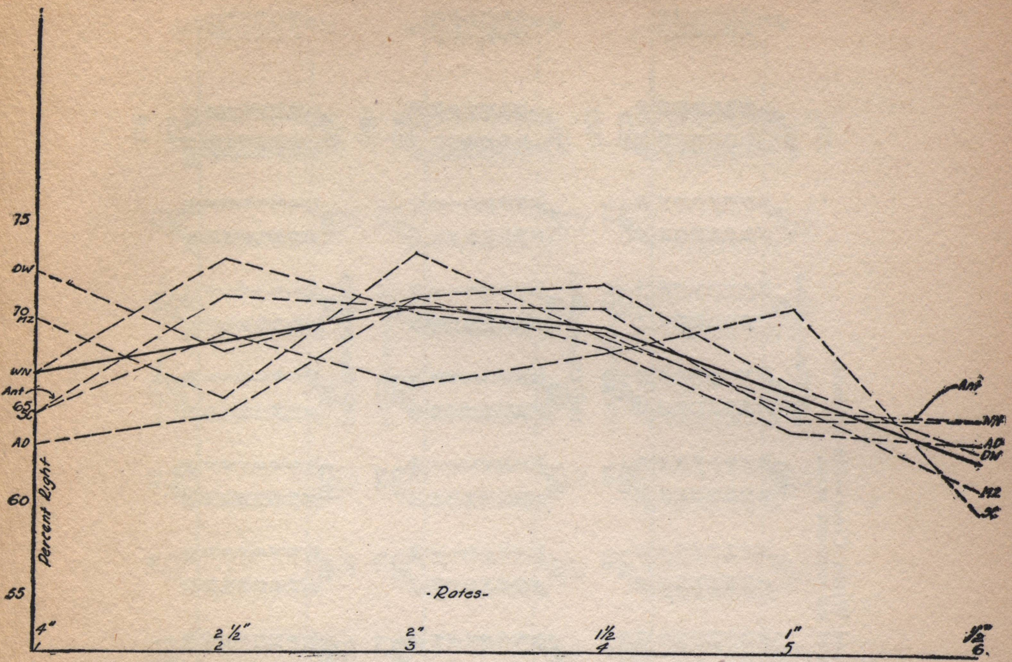
The exposure intervals were regulated by a bell metronome. Six intervals were used, 4″, 2½″, 2″, 1½″, 1″ ½″: the intervals, except the ½″, being marked by four beats of the metronome, with bell on the 4th beat. For the last interval, the bell rang on every other beat with the metronome set for 240 (runner removed). On each bell the experimenter dropped a card, thus making the exposure for the determined interval as described above. This procedure was continued until all 12 cards had been shown. Judgments, as they were spoken by the observer, were recorded on a specially prepared blank by a third person. The writer, who acted as experimenter throughout, practiced for a considerable time until he could turn the cards with regularity and smoothness, and there was little or no confusion in the presentation. None of the observers complained of movements sufficient to disturb their perception of the lines as they were successively exposed.

PRACTICE AND FATIGUE

To avoid the massing of whatever practice effect there might be at any one rate of exposure, the series were taken according to a regular plan: 20 at one rate, 20 at another rate, etc. As never more than 180 judgments were recorded at any one sitting, it was not believed that the factors of fatigue or eyestrain need be considered.

RESULTS

The six men, Mz, Dw, Wn, Ad, Sc, Ant, who acted as subjects in the weight-lifting experiments served as observers in the present experiment also. Table X contains the records of each individual observer in % of right cases of all 12 lines; also the % of right cases for each comparison line as well as the total % accuracy for the given rate. The results at any given rate are based on 1440 observations.



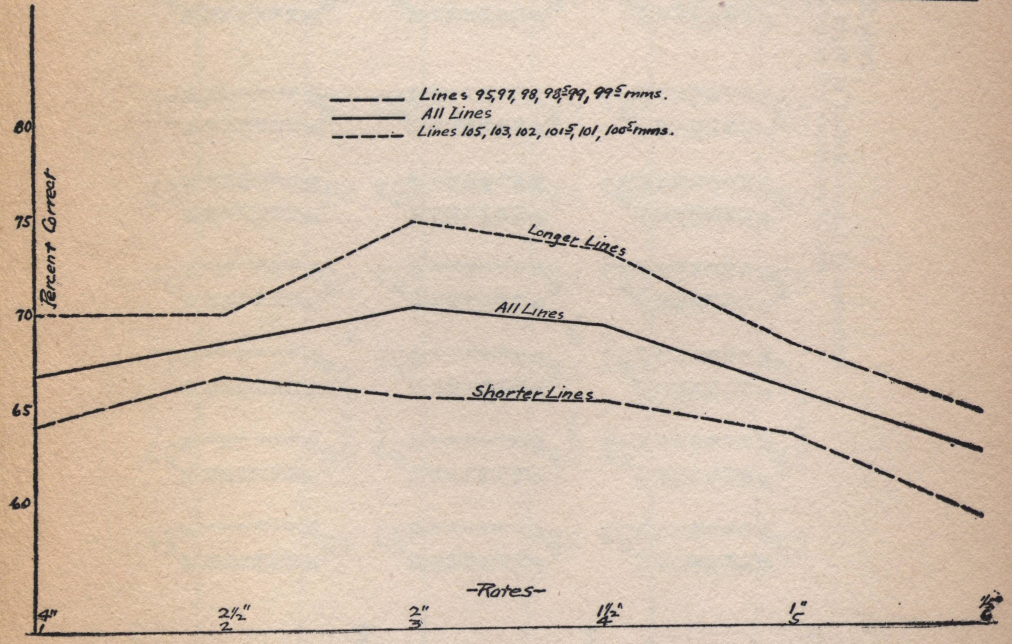


Diagram 5.—Combined accuracy record for 6 O's _________ Also individual records ....1440 judgments at each rate

Diagram 6.—Combined accuracy record for all 12 lines; also for 6 lines longer and 6 lines shorter than the standard 100 mm. line.

Table X

Perception of Lines:—Method of Right and Wrong Cases:—Six subjects, 8640 Observations—1440 at each of six exposure rates.

Rate 1 4" — 1440 Observations

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Tot.		%
Obs.	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
Mz	17	3	16	4	16	4	10	10	10	10	12	8	10	10	12	8	16	4	16	4	15	5	17	3	167	73	69.6
Dw.	16	4	16	4	17	3	14	6	13	7	15	5	12	8	10	10	12	8	13	7	17	3	18	2	173	67	72.1
Wn.	15	5	12	8	12	8	15	5	12	8	10	10	10	10	14	6	13	7	14	6	17	3	16	4	160	80	66.7
Ad.	12	8	14	6	13	7	10	10	8	12	11	9	13	7	14	6	11	9	14	6	16	4	15	5	151	89	62.9
Sc.	17	3	12	8	12	9	12	8	8	12	9	11	10	10	12	8	16	4	16	4	15	5	17	3	155	85	64.6
Ant.	16	4	14	6	17	3	11	9	10	10	8	12	11	9	14	6	14	6	12	8	14	6	14	6	155	85	64.6
Sum.	93	27	84	36	86	34	72	48	61	59	65	55	66	54	76	44	82	38	85	35	94	26	97	23	961	479	
%R.	77.5		70.0		71.7		60.0		50.8		54.2		55.0		63.3		68.3		70.8		78.3		80.0		66.73		
Ad.	6.7		6.7		11.7		8.3		7.8		9.2		5.0		6.7		8.3		6.2		5.0		5.8				
PE (Aver.)																									1.03		

Rate 2 2½" — 1440 Observations

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Tot.		%
Obs.	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
Mz.	16	4	15	5	13	7	11	9	10	10	10	10	12	8	12	8	13	7	14	6	15	5	16	4	157	83	65.4
Dw.	18	2	16	4	16	4	12	8	13	7	10	10	11	9	11	9	10	10	12	8	17	3	17	3	163	77	67.9
Wn.	17	3	13	7	14	6	13	7	14	6	11	9	12	8	14	6	16	4	15	5	18	2	18	2	175	65	72.9
Ad.	13	7	12	8	17	3	15	5	10	10	10	10	11	9	10	10	14	6	11	9	17	3	15	5	155	85	64.6
Sc.	16	4	14	6	12	8	15	5	12	8	9	11	10	10	15	5	12	8	16	4	15	5	19	1	165	75	68.8
Ant.	15	5	15	5	14	6	14	6	13	7	12	8	12	8	12	8	15	5	15	5	16	4	17	3	170	70	70.8
Sum.	95	25	85	35	86	34	80	40	72	48	62	58	68	52	74	46	80	40	83	37	98	22	102	19	985	455	
%R.	79.2		70.8		71.7		66.7		60.0		51.7		56.7		61.7		66.7		69.2		81.7		85.0		68.40		
Ad.	6.2		5.8		7.3		6.7		5.8		4.0		3.3		7.3		8.3		7.8		5.0		4.2				
PE. (Aver.)																									.967		

Rate 3 2" — 1440 Observations

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Tot.		%
Obs.	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
Mz.	18	2	16	4	14	6	12	8	10	10	14	6	14	6	14	6	12	8	15	5	17	3	20	0	176	64	73.3
Dw.	14	6	18	2	13	7	10	10	15	5	15	5	8	12	14	6	14	6	14	6	17	3	19	2	170	70	70.8
Wn.	18	2	16	4	12	8	14	6	15	5	11	9	8	12	12	8	12	8	15	5	19	1	16	4	168	72	70.0
Ad.	15	5	17	3	10	10	12	8	8	12	12	8	14	6	16	4	16	4	14	6	16	4	20	0	170	70	70.8
Sc.	17	3	10	10	14	6	10	10	6	14	10	10	10	10	14	6	16	4	17	3	17	3	18	2	159	81	66.2
Ant.	16	4	15	5	15	5	14	6	10	10	6	14	12	8	12	8	16	4	17	3	18	2	18	2	169	71	70.4
Sum.	98	22	92	28	78	42	72	48	64	46	68	52	66	54	82	38	86	34	92	28	104	16	110	10	1012	428	
%R.	81.7		76.7		65.0		60.0		53.3		56.6		55.0		68.3		71.7		76.7		86.7		91.7		70.28		
Ad.	6.7		9.4		6.7		6.7		14.4		11.7		11.7		5.6		8.3		5.7		4.0		5.7				
PE. (Aver.)																									1.22		

Rate 4 1½"

1440 Observations

Obs.	95 R	95 W	97 R	97 W	98 R	98 W	98.5 R	98.5 W	99 R	99 W	99.5 R	99.5 W	100.5 R	100.5 W	101 R	101 W	101.5 R	101.5 W	102 R	102 W	103 R	103 W	105 R	105 W	Tot. R	Tot. W	% R
Mz.	14	6	14	6	12	8	15	5	14	6	8	12	10	10	14	6	15	5	15	5	17	3	17	3	165	75	68.8
Dw.	17	3	15	5	13	7	14	6	13	7	10	10	11	9	16	4	15	5	14	6	16	4	18	2	172	68	71.7
Wn.	16	4	14	6	13	7	15	5	10	10	8	12	9	11	15	5	16	4	14	6	17	3	19	1	166	74	69.2
Ad.	15	5	17	3	15	5	13	7	8	12	11	9	10	10	12	8	15	5	13	7	17	3	18	2	164	76	68.3
Sc.	16	4	12	8	14	6	12	8	11	9	12	8	8	12	15	5	15	5	14	6	15	5	19	1	163	77	67.9
Ant.	16	4	15	5	15	5	13	7	12	8	9	11	7	13	14	6	14	6	16	4	18	2	20	0	169	71	70.4
Sum.	94	26	87	33	82	38	82	38	68	52	58	62	55	65	86	34	90	30	86	34	100	20	111	9	999	441	
%R.	78.3		72.5		68.3		68.3		56.7		48.3		45.8		71.7		75.0		71.7		83.3		92.5		69.4		
Ad.	4.0		5.8		5.0		5.0		8.3		6.7		5.8		5.0		1.7		4.0		4.0		5.0				
PE. (Aver.)																									1.14		

Rate 5 1"

1440 Observations

Obs.	95 R	95 W	97 R	97 W	98 R	98 W	98.5 R	98.5 W	99 R	99 W	99.5 R	99.5 W	100.5 R	100.5 W	101 R	101 W	101.5 R	101.5 W	102 R	102 W	103 R	103 W	105 R	105 W	Tot. R	Tot. W	% R
Mz.	16	4	15	5	13	7	14	6	11	9	9	11	8	12	10	10	12	8	14	6	17	3	18	2	157	83	65.4
Dw.	17	3	13	7	12	8	13	7	10	10	10	10	12	8	12	8	12	8	15	5	16	4	17	3	159	81	66.3
Wn.	18	2	14	6	12	8	10	10	9	11	12	8	6	14	12	8	14	6	15	5	17	3	17	3	156	84	65.0
Ad.	16	4	13	7	14	6	13	7	10	10	8	12	10	10	10	10	14	6	13	7	16	4	16	4	153	87	63.0
Sc.	18	2	14	6	15	5	15	5	12	8	11	9	11	9	14	6	15	5	15	5	14	6	15	5	169	71	70.4
Ant.	16	4	13	7	10	10	12	8	10	10	9	11	9	11	12	8	13	7	16	4	17	3	18	2	155	85	64.6
Sum.	101	19	82	38	76	44	77	43	62	58	59	61	56	64	70	50	80	40	88	32	97	23	101	19	949	91	
%R.	84.2		68.3		63.3		64.2		51.7		49.2		46.7		58.3		66.7		73.3		80.8		84.2		65.9		
Ad.	4.2		3.3		6.6		6.1		3.9		5.8		8.3		5.7		5.0		4.0		4.2		4.5				
PE. (Aver.)																									1.11		

Rate 6 ½"

1440 Observations

Obs.	95 R	95 W	97 R	97 W	98 R	98 W	98.5 R	98.5 W	99 R	99 W	99.5 R	99.5 W	100.5 R	100.5 W	101 R	101 W	101.5 R	101.5 W	102 R	102 W	103 R	103 W	105 R	105 W	Tot. R	Tot. W	% R
Mz.	16	4	14	6	13	7	14	6	6	14	6	14	8	12	10	10	12	8	16	4	14	6	17	3	146	94	60.9
Dw.	17	3	16	4	14	6	10	10	10	10	12	8	6	14	10	10	14	6	10	10	15	5	17	3	151	89	62.9
Wn.	12	8	10	10	12	8	12	8	12	8	10	10	14	6	14	6	14	6	14	6	13	7	16	4	155	85	64.6
Ad.	13	7	16	4	10	10	12	8	8	12	14	6	10	10	16	4	14	4	12	8	16	4	11	9	152	88	63.3
Sc.	12	8	13	7	10	10	10	10	8	12	6	14	12	8	12	8	14	6	16	4	15	5	15	5	143	97	59.6
Ant.	16	4	12	8	15	5	13	7	10	10	12	8	8	12	12	8	15	5	14	6	12	8	16	4	155	85	64.6
Sum.	86	34	81	39	74	46	71	49	54	66	60	60	58	62	74	46	85	35	82	38	85	35	92	28	902	538	
%R.	71.7		67.5		61.7		59.3		45.0		50.0		48.3		61.7		70.8		68.3		70.8		76.7		62.64		
Ad.	10.0		9.2		8.3		5.8		8.3		13.3		11.7		9.0		4.5		9.0		5.8		7.7				
PE. (Aver.)																									1.13		

At first blush it might seem that the more time an observer is allowed for discriminating the difference between two lines, the more accurate he will be. This is not true, however, at least for the conditions of this experiment, as Table X and Diagram 5 make clear. The course of accuracy rises slightly from Rate 1 to Rate 3; there is little change from Rate 3 to Rate 4, and a fairly definite "slump" in accuracy through Rates 5 and 6. The individual records (Diagram 5) though they show some irregularity, as might be expected, are very close together, the greatest divergences coming at Rates 1 and 2. Reference to Table X shows that for the lines less than 100 mm. only one, 98 mm. was perceived most accurately at Rate 1, this Rate being as good but no better than Rate 2. For lines greater than 100 mm. Rate 1 is nowhere productive of the greatest accuracy.

As brought out in the previous experiment, there are two ways of studying changes in accuracy corresponding to changes in speed, i.e. time given for discriminating between two stimuli. One is to compare the number of accurate responses from the subjects at the different rates, and the other to compare the right cases for the variable stimuli at the different rates of exposure. The second method gives the more detailed information. Both of these methods were used in the weight-lifting experiments. In the present experiment, however, I have combined the six lines shorter than the standard, and the six lines longer than the standard, rather than taking each comparison line separately. This was done because the lines differ so slightly from each other that I did not think it worth while considering each separately. The accuracy curves for the longer and shorter lines as well as the curve for all 12 lines are given in Diagram 6.

Tables XI and XII give the data from which the curves in Diagram II were plotted, and the reliabilities of the differences between the rates.

The PE (true-obt. Av.) were calculated from the formula $\text{PE (t-o Av.)} = \frac{\text{PE (dis.)}}{\sqrt{\text{N}}}$ and the PE (diffs.) from the formula: $\text{PE (tr-obt. diff. A-B)} = \sqrt{\text{PE}^2 \text{ (t-oA)} + \text{PE}^2 \text{ (t-oB)}}$. Diagram 6 shows that the curve for the shorter lines reaches its highest point at Rate 2, and hence the records for the other 5 rates are compared with it. There is little evidence of any

TABLE XI
(All 12 Lines)

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5	Rate 6
Aver.	66.73	68.40	70.28	69.38	65.90	62.64
PE (Av)	1.03	.967	1.22	1.14	1.11	1.13
Diff (Av) from R–3	3.55	1.88	——	.90	4.38	7.64
PE (diff) from R–3	1.59	1.56	——	1.67	1.65	1.66

Probability that true diff. between Rates 3 & 1=0 or less=664 in 10,000 (Roughly 1 in 15)
" " " " " " 3 & 2=0 or less=2090 in 10,000 (Roughly 1 in 5)
" " " " " " 3 & 4=0 or less=3553 in 10,000 (Roughly 1 in 3)
" " " " " " 3 & 5=0 or less= 369 in 10,000 (Roughly 1 in 28)
" " " " " " 3 & 6=0 or less= 10 in 10,000 (Roughly 1 in 1000)

TABLE XII
(Lines 95-97-98-98.5-99-99.5)

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5	Rate 6
Aver.	64.03	66.70	65.60	65.40	63.50	59.20
PE (Av)	1.56	1.34	1.78	1.37	1.47	1.59
Diff (Av) from R–2)	2.67	——	1.10	1.3	3.2	7.5
PE (diff) from R–2)	2.05	——	2.23	1.92	1.99	2.08

Probability that true diff. bet. Rates 2 and 1=0 or less=1003 in 10,000 (Roughly 1 in 10)
" " " " " " 2 and 3=0 or less=3679 in 10,000 (Roughly 1 in 3)
" " " " " " 2 and 4=0 or less=3255 in 10,000 (Roughly 1 in 3)
" " " " " " 2 and 5=0 or less=1388 in 10,000 (Roughly 1 in 7)
" " " " " " 2 and 6=0 or less= 75 in 10,000 (Roughly 1 in 134)

(Lines 105-103-102-101-100.5)

	Rate 1	Rate 2	Rate 3	Rate 4	Rate 5	Rate 6
Aver.	70.00	70.00	75.00	73.3	68.3	64.7
PE (Av)	1.31	1.41	1.61	1.70	1.66	1.58
Diff (Av) from R–3)	5.0	5.0	——	1.7	6.7	10.3
PE (diff) from R–3)	2.07	2.14	——	2.34	2.31	2.25

Probability that true diff. bet. Rates 3 and 1=0 or less=520 in 10,000 (Roughly 1 in 18)
" " " " " " 3 and 2=0 or less=572 in 10,000 (Roughly 1 in 16)
" " " " " " 3 and 4=0 or less=3112 in 10,000 (Roughly 1 in 3)
" " " " " " 3 and 5=0 or less=252 in 10,000 (Roughly 1 in 40)
" " " " " " 3 and 6=0 or less= 12 in 10,000 (Roughly 1 in 800)

precise optimal rate for accuracy, the change from Rate 2 to Rate 4 being so slight as to be almost negligible. The rise in accuracy from Rate 1 to 2, and the "drop" from Rate 4 to

6, are, however, fairly reliable—particularly the last mentioned change.

For the lines greater than the standard, Rate 3 is the point of greatest accuracy, though the chances are small of a difference between this rate and Rate 4. The evidence in favor of Rate 3 is considerably better in comparison with the other rates, as the reliability table shows: the decrease through Rates 5 and 6 being much more definite and probable.

Apparently there is no rate which can be designated, finally, as the "optimal" exposure interval for all 12 lines; though the accuracy is highest at Rates 3 and 4. About all that can be fairly said is that the differences between the variable and the standard lines are perceived as well when 1″ is given for comparison as when 4″ are given; and that when 2½″, 2″, 1½″, are allowed, the comparisons are slightly more accurate than when 4″, 1″, or ½″ are given. If we remember (as pointed out in the experiment on lifted weights) that the range of accuracy, which we may expect, is limited and that a rather large number of judgments were taken at each rate, the balance in favor of Rates 3 and 4 is believed to be relatively high. It is very probable that the fluctuations in accuracy from Rate 2 to Rate 4 are so slight as to show no real difference in the subject's ability to discriminate at these different intervals: in fact, they suggest chance factors.

Diagram 7 shows the corresponding changes in speed (decreased interval and accuracy (perception of differences). With Rate 1 as unit, 100%, Rate 2, measured from Rate 1, becomes 102.6, Rate 3, 105.3, Rate 4, 103.9, Rate 5, .987, and Rate 6, .938. It is evident that an increase in speed of exposure of 60% produced an increase of 2.6% in the accuracy of perception; an increase of 100% in exposure rate produced a corresponding increase of 5.3% in accuracy measured from Rate 1; an increase of 16% in speed produced an increase of 3.9% in accuracy. At Rate 5, however, an increase of 300% in exposure rate caused the accuracy to fall 1.3% below the level of Rate 1, while at Rate 6, with the speed increased 700%, the accuracy decreased 6.2% from the level of Rate 1. As in the case of lifted weights, speed and accuracy are directly though not proportionally related, up to Rate 3,—an interval of 2″; after this point the two variables are inversely related, a decrease in exposure interval—i.e. increase in rate—causing a decrease in accuracy.

The results outlined above are very similar to those got in the weight-lifting experiment, and the explanation must be very much the same in both cases. Probably what actually happens is that the observer's decision is made as soon as his eyes "run over" the lines, and that the time left is simply unused. When much time is left, fluctuations of attention, monotony, irrelevant details, etc., creep in; when the cards follow each other very rapidly, confusion ensues, due partly to the fact that one vocalization follows another so quickly that the shift from one to another is difficult—and oftentimes not made. Other factors which may be responsible for changes in accuracy have been described by Müller[76] as "casual" or "incidental" errors. Some of these, called "psychological errors," apply well here. Such errors are due to (1) varying degree and direction of attention; (2) variation among the elements of the complex determining judgment; (3) degree and direction of expectation; (4) influence of the order of the preceding experiments. Errors in the last named are due to slip comparisons, shift of standard, change in the concentration of attention, and inertia or habituation of judgment.

The "optimal" exposure interval is, therefore, that interval which permts the observer to exploit the lines, and speak his judgment without undue haste, or too long a lapse before the next card appears. The introspections of the observers, as well as the observations of the experimenter confirm this statement. Frequently, at Rate, I noticed a tendency on the part of the subject to hurry the experiment along—judgments were spoken as soon as the card was exposed, and often the observer's eyes wandered about the room coming back with a jerk when the bell rang for the appearance of another card. On the other hand, at the conclusion of a series of 20 comparisons at Rate 6, an observer would often say: "I meant to say 'shorter, a' in one of those last judgments, but I simply said 'longer, a' before I could stop myself." With a number of possible responses (six in all) all in equal readiness, it is easy to understand how these "false reactions" could happen.

The introspections of the subjects in this experiment are given subject to the same qualifications made for the introspections in the previous experiment.

[76]Müller: Die Gesichtpunkte und die Tatsachen der psychophysichen Methodik, 1904, 109-112.

INTROSPECTIONS

Mz.—Had no general method. Moved my eyes across the cards, usually from left to right, and decided in term of the first impression. About the same degree of confidence throughout.

Dw.—I used no particular method at the slow rates. At the fast rates, tried to get an impression of the standard line and compare in terms of it. Occasionally I glanced back at the standard when uncertain; not much change in confidence.

Wn.—Varied by method considerably; finally settled on fixating the central dividing line, and glancing quickly to the left and right. Usually seemed to have a pretty good idea of the standard line, and did not look at it often. I was less confident at the shorter intervals.

Ad.—Used quick eye movements. I had no particular plan so far as I know. Was less confident as the intervals grew shorter.

Sc.—Usually took a quick glance from left to right. Guessed sometimes at the small differences. Never felt particularly confident; used "b" when I was pretty sure.

Ant.—I soon seemed to have a pretty clear idea of the standard. Then I glanced quickly at the comparison line, and" checked" up by looking back at the standard if uncertain. Was fairly confident, though I guessed some times at the short intervals.

In experiments on Lifted Weights the stimuli are presented successively and the second stimulus is always compared with the one immediately preceding. In this experiment the task set the observer is different, in that the standard and the variable are always presented simultaneously and comparison is made directly. No "set" or "absolute impression" is necessary, though the observer often forms a more or less clear visual impression of the standard (see Fernberger[77]). Such an "impression" can hardly be an influential factor, however, in an experiment like the present, as in experiments on lifted weights: for the observer can always "refresh" his memory, when uncertain, by a quick glance at the standard. Accuracy, therefore, must depend largely (after allowance is made for the personal equation) on visual acuity, attention to the task,

[77]An Introspective Analysis of the Process of Comparing, Psy. Monogr., 1919, 103-110.

practice. Münsterburg[78] finds that in the estimation of simultaneously presented lengths and average error varies from 1.1% to 2.3%, when the eyes are permitted to move freely, while the average error varies from 3.7% to 4.9% when the eyes remain fixed. He takes this as clear proof of the dependence of our estimates of linear magnitudes on muscular sensations.

One source of error in this experiment, which has been touched upon, but not fully considered, lies in the fact that the observers were required to give their answers aloud, rather than express them by releasing a key, raising a hand or by some other mechanical device. This was certainly a source of error at Rate 6, where shift from one vocal set to another was difficult Still it could not have been the only source of error, here or elsewhere, as the accuracy increased appreciably from Rate 1 to Rate 3: from an interval of 4″ to one of 2″. None of the subjects had any apparent difficulty in speaking their decisions at Rates 4 or 5, and as a matter of fact Rate 5 was as accurate at Rate 1. It is fully recognized that the vocal recording of judgments restricts the exposure interval, as it would be impossible to speak a judgment when the cards are exposed, say for ¼″. However, the method used in this experiment precluded the use of exposure rates below ½″, as it was mechanically impossible to present the cards at a rate faster than that, while it was not the object of the experiment to find the shortest interval at which judgment could be made, but only to trace the accuracy of spoken judgments over a fairly wide range of exposure intervals. The decrease in accuracy from Rate 3 on made the use of rates faster than 6 give little promise of an upward trend of the accuracy curve; while the rise in the accuracy curve from Rate 1 did not give much hope of greater accuracy below the slowest rate used. It is worthy of note, too, that since all six observers used only "c" at Rate 6, that the vocal response was not much more difficult than releasing a key.

Diagram 6 shows that the lines greater than 100 mm. were perceived more accurately throughout, than those less than the standard. The exceptions, in every case but two, occurred with those lines which differed by .5 mm. from the standard, where the accuracy was always close to 50%. This more accurate estimation of the longer lines may be due to the ten-

[78]Op. cita. p. 178-179.

dency to overestimate the variable as compared with the standard, which Munsterburg reports, and which he explains as due to the observer's tendency to glance quickly and indirectly at the standard line while the variable is examined more closely. These cursory glimpses of the standard, taken oftentimes as "checkups" on one's impression, result in its underestimation.

In this experiment the direction of judgment was fixed; variable always on the right, standard on the left. This, doubtless, introduced a constant space error. But since this error was present at all six rates, it does not vitiate a comparison of results,—which is the real object of the experiment. For this reason a series of judgments with the variable and standard in reverse positions was not taken.

Henmon[79] finds evidence of the more accurate perception of the shorter of two given lines. Using two lines only, 20 mm. and 20.3 mm. he reports a "curious constant error" in that his three observers give quicker and more confident judgments when the direction of judgment was from the longer to the shorter line. The observers reacted one-half of the time to the longer line and one-half of the time to the shorter line. These results are contrary to those got in this experiment, but the two experiments are hardly comparable. Henmon used only two lines, both comparatively short, direction of judgment was not fixed, and the exposure time was variable, exposure continuing until the observer made a judgment. Also, the two lines were separate and not joined as in this experiment. Judgment was expressed by releasing a key, and time of discrimination was recorded by the Hipp Chronoscope.

Table XIII shows the number of times the various degrees of confidence were used by the different observers, and the % of *a*'s and *b*'s compared with the % of right cases for each line difference. As in the weight-lifting experiments, the confidence decreases regularly with the decrease in right cases, but the degree of confidence is hardly an accurate measure of the reliability of an individual's records for accuracy. In spite of instructions as to the meaning of the terms *a, b, c,* the different observers gave them very different values. Table XIV, for example, shows that Mz was entirely confident at Rates 4 and 5, while his accuracy records at the same rates was 68.8% and 65.8%. Ant and Ad used a majority of *b's* and

[79]Time and Accuracy of Judgment, Psy. Rev., 1811, *18*, 189ff.

c's while Sc never used *a*, and Wn used *a* only 20 times in 1440 judgments. Henmon[80] reports that one of his observers used *a* 90.4% of the time, while another used *a* only 9.3% of the time. At Rate 6 all of the observers used *c*. This may have been due to a feeling that "I should be less confident" rather than to a real loss of confidence; for accuracy was still fairly high above 50%.

These results indicate the difficulty of getting a real scale for confidence in such measures as these. The relation of confidence to accuracy seems to be an individual affair, and it is impossible to say whether observers who are usually confident are generally more or less accurate than those who are cautious.

Individual differences in the accuracy of comparison were not very pronounced except possibly at Rates 1 and 2. Dw and Wn, both classified in the previous experiment as quick in giving their judgments, and most accurate at the faster rates, are no better than Ad or Ant, both classed as "cautious" in the weight experiment and best at the slow rates. With the possible exception of Sc, the observers seem to possess nearly the same ability to perceive linear differences. In the use of the confidence categories, the observers follow very closely their records in the weight lifting experiment: Mz and Dw use *a* most of the time, Wn and Sc *c*, and Ad and Ant use all three terms with a strong "leaning" to the *c* category.

CONCLUSIONS

1.—Under the conditions of this experiment, the accuracy of perception of differences between the 100 mm. standard and variables ranging from 5 mm. above to 5 mm. below the standard does not change appreciably whether the exposure interval is 2½″, 2″, or 1½″. When the exposure interval is increased to 4″ or decreased to 1″ there is a relatively slight, but definite, "drop" in accuracy. At ½″ exposure there is a pronounced decrease in the accuracy of perception.

2.—The variable lines longer than the standard give higher %s of right cases than those shorter than the standard. This indicates a tendency to overestimate the variable line.

3.—The six shorter variables are perceived a little more accurately at Rate 1 to Rate 4. The six longer lines are perceived best at Rate 3, and only slightly less accurately at Rate 4.

[80]Time and Accuracy of Judgment, Psy. Rev. 1911, 18, 189ff.

TABLE XIII

Showing how many a's, b's, and c's were given by each observer for each comparison line; also a comparison of the % right for each line with the Accuracy record for the same line.

Rate 1

	95	97	98	98.5	99	99.5	100.5	101	101.5	102	103	105	Total
	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c
Mz.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Dw.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Wn.	18 2	8 12	6 14	2 18	2 18	4 16	6 14	4 16	12 8	8 12	10 10	6 4	96 144
Ad.	8 12	8 12	14 6	16 4	14 6	10 10	14 6	10 10	10 10	12 8	12 8	12 8	140 100
Sc.	0 20	2 18	2 18	2 18	0 20	6 14	8 12	10 10	6 14	6 14	10 10	12 8	64 176
Ant.	12 8	6 14	6 14	8 12	6 14	8 12	2 18	6 14	14 6	8 12	12 8	6 14	97 146
Tot.	78 42	64 56	68 52	68 52	62 58	68 52	70 50	70 50	82 38	74 46	84 36	86 34	874 566
%R.	77.5	70	71.7	60	50.8	54.2	55	63.3	68.3	70.8	78.3	80.8	66.73
%ab	65	53	57	57	52	57	58	58	68	62	70	72	60.7

Rate 2

	95	97	98	98.5	99	99.5	100.5	101	101.5	102	103	105	Total
	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c
Mz.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Dw.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Wn.	8 12	6 14	0 20	0 20	2 18	0 20	0 20	0 20	4 16	2 18	4 16	2 18	28 212
Ad.	14 6	10 10	10 10	20 0	8 12	10 10	10 10	10 10	12 8	16 4	16 4	18 2	154 86
Sc.	12 8	10 10	8 12	6 14	6 14	6 14	6 14	2 18	2 18	6 14	8 12	10 10	82 158
Ant.	10 10	2 18	2 18	8 12	4 16	2 18	0 20	2 18	4 16	6 14	6 14	2 18	48 192
Tot.	84 36	68 52	60 60	74 46	60 60	58 62	56 64	54 66	62 58	70 50	74 46	72 48	792 648
%R.	79.2	70.8	71.7	66.7	60.0	51.7	56.7	61.7	667	69.2	81.7	85.0	68.40
%ab	70	57	50	62	50	48	47	45	52	58	62	60	55.0

Rate 3

	95	97	98	98.5	99	99.5	100.5	101	101.5	102	103	105	Total
	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c	ab c
Mz.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Dw.	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	20 0	240 0
Wn.	8 12	4 16	0 20	2 18	4 16	0 20	4 16	0 20	2 18	6 14	6 14	10 10	46 194
Ad.	14 6	16 4	14 6	14 6	14 6	14 6	14 6	12 8	8 12	16 4	16 4	16 4	168 72
Sc.	10 10	8 12	4 16	2 18	4 16	4 16	8 12	4 16	8 12	4 16	10 10	10 10	76 164
Ant.	12 8	4 16	6 14	6 14	8 12	8 12	8 12	4 16	2 18	2 18	6 14	12 8	78 162
Tot.	84 36	72 48	64 56	64 56	70 50	66 54	74 46	60 60	60 60	78 42	78 42	88 32	848 592
%R.	81.7	76.7	65	60	53.3	56.7	55	68.3	71.7	76.7	86.7	91.7	70.28
%ab	70	60	53	53	58	55	62	50	50	65	65	73	58.8

Rate 4

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Total	
	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c
Mz.	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240	0
Dw.	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240	0
Wn.	6	14	6	14	0	20	2	18	0	20	0	20	4	16	2	18	0	20	2	18	4	16	4	16	32	208
Ad.	14	6	16	4	12	8	12	8	16	4	10	10	10	10	16	4	12	8	14	6	16	4	18	2	166	74
Sc.	2	18	4	16	16	4	4	16	0	20	2	18	2	18	6	14	8	12	8	12	1	28	10	10	74	166
Ant.	8	12	2	18	10	10	10	10	2	18	66	14	4	16	6	14	4	16	4	16	0	20	10	10	66	174
Tot.	70	50	68	52	78	42	68	52	58	62	58	62	60	60	70	50	64	56	68	52	72	48	84	36	818	622
%R.	78.3		72.5		68.3		68.3		56.7		48.3		45.8		71.7		75		71.7		83.3		82.5		69.4	
%ab	58		57		65		57		48		48		50		58		53		57		60		70		56.8	

Rate 5

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Total	
	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c
Mz.	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240	0
Dw.	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240	0
Wn.	14	6	0	20	2	18	14	6	6	14	2	18	6	14	0	20	4	16	4	16	2	18	6	14	60	180
Ad.	12	8	14	6	10	10	14	6	16	4	16	4	8	12	14	6	12	8	20	0	16	4	14	6	166	74
Sc.	4	16	0	20	2	18	4	16	0	20	4	16	6	14	6	14	6	14	2	18	10	10	8	12	52	188
Ant.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Tot.	70	50	64	66	54	66	72	48	62	58	62	58	60	60	60	60	62	58	66	54	68	52	68	52	758	682
%R.	84.2		68.3		63.3		64.2		51.7		49.2		46.7		58.3		66.7		73.3		80.8		84.2		65.9	
%ab	58		53		45		60		52		52		50		50		52		55		57		57		52.6	

Rate 6

	95		97		98		98.5		99		99.5		100.5		101		101.5		102		103		105		Total	
	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c	ab	c
Mz.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Dw.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Wn.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Ad.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Sc.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Ant.	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	20	0	240
Tot.	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	120	0	1440
%R	71.7		67.5		61.7		59.3		45		50		58.3		61.7		70.8		68.3		70.8		76.7		62.64	
%ab	0		0		0		0		0		0		0		0		0		0		0		0		0	

TABLE XIV

Percentage of Times each Degree of Confidence was Used.

			A			
Rates	1	2	3	4	5	6
Mz	78	100	93	100	100	0
Ad	10	10	20	13	10	–
Dw	87	93	90	100	97	100
Wn	5	1	1	–	2	–
Ant	22	17	10	10	–	–
Sc	–	–	–	–	–	–
			B			
Rates	1	2	3	4	5	6
Mz	22	–	–	–	–	–
Ad	50	60	20	56	60	–
Dw	13	7	10	–	3	–
Wn	35	11	18	13	23	–
Ant	18	3	20	17	20	–
Sc	27	34	36	30	20	–
			C			
Rates	1	2	3	4	5	6
Mz	–	–	7	–	–	100
Ad	40	30	60	31	30	100
Dw	–	–	–	–	–	100
Wn	60	88	81	87	75	100
Ant	60	80	70	73	80	100
Sc	73	66	64	70	80	100

4.—Confidence increases as the difference between the standard and variable increases. However, the degree of confidence given is largely an individual matter, and is not a very reliable index of objective accuracy. Observers range from those who report themselves as always sure, to those who never report themselves as sure.

5.—The individual differences are almost negligible. Except at Rate 1 the six observers are very close together.

3. Speed and Accuracy in Comparing Handwriting Specimens.

PROBLEM

Like the two preceding experiments the present experiment is concerned with the speed-accuracy relation in the perception of differences. As material for comparison I used specimens of handwriting, the specific problem being to discover, given a specimen of handwriting as a standard, how accurately other specimens can be compared with it, and a judgment of "better" or "worse" given. The speed, i. e. time allowed for perception and comparison, was varied by the experimenter and the accuracy was gauged by the number of correct comparisons.

In such material as handwriting, the perceptions of differences which are capable of determining the direction of judgment is more difficult and more variable than in the case of weights and lines. For many factors such as general appearance of the writing, character, maturity, masculinity, size, shape, spacing of letters, idiosyncrasies in crossing t's, ending g's, y's, etc., regularity or "cramped" appearance of the characters, influence the decision: while the prejudice of the observer for some particular variety of handwriting complicates the process with a distinctly personal, and hence uncontrolled element. Thorndike,[81] apropos this subject, notes: "Being far, far more alike in sense organs and muscles than in central connections of neurones, we agree far better in comparing lines and weights than in comparing handwriting or poems."

It might seem from the foregoing considerations, that the choice between two specimens of handwriting is a purely personal affair, and is based on the individual's self-constituted standard alone. This is not strictly true, however, as the existence of handwriting scales shows that there are pretty well recognized norms in terms of which we judge handwriting as "good" or "bad;" and on which we all largely agree. Pintner[82] found, with 330 observers, a correlation of +.98 between 24 samples of handwriting graded by the Thorndike and the Ayres Scales. Thorndike[83] says that in using his scale, competent teachers without training will make an error of about .9 of a step in judging a sample, on the average, and that with practice judgments become more precise. Legibility, which was the criterion used by Ayres in constructing his scale, is probably the most important factor in determining the average person's norm for handwriting; though beauty, character, ease, etc., which Thorndike considered as well as legibility, certainly help determine it.

MATERIAL AND PROCEDURE

The material for this experiment consisted of 75 specimens of handwriting selected from nearly 200 printed specimens, all of which had been carefully graded by the Thorndike Scale. Samples which fell below 8 or went above 16 on this scale (the Scale ranges from 4 to 18 in steps of 1) were discarded, so that the specimens used might not be so far apart on the scale

[81]T. C. Record, 'Handwriting" 1910, *11*, p. 42 note.

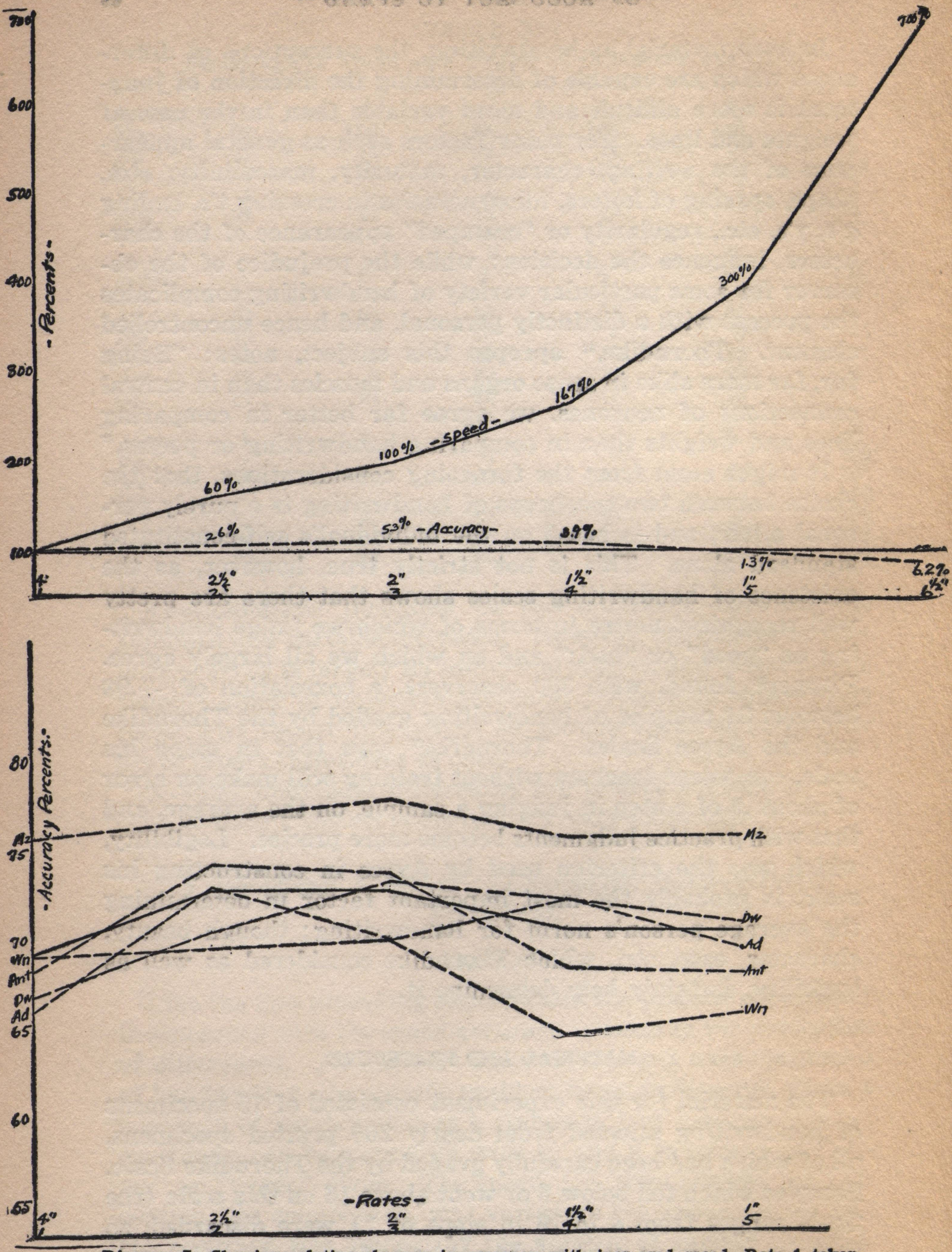


Diagram 7.—Showing relative changes in accuracy with increased speed. Rate 1 taken as 100 for both accuracy and speed.

Diagram 8.—Combined accuracy record for 5 O's and individual records for each. 5,250 comparisons at each rate.

as to be always recognized as different and hence make judgment too easy. Actually one specimen graded at 7.1 by the scale was included by accident, but this was the only sample below 8, and none above 16 were employed.

The 75 specimens were grouped into 5 sets of 15 each, the sets being as nearly as possible of equal value:—containing samples of approximately the same degree of excellence as measured by the Scale. Each specimen was mounted on cardboard 8″ by 2″ in size, and was numbered on the reverse side with two numbers, one for the group and one for the position in the group.

The method used in presenting the cards was that of Paired Comparisons. At the beginning of an experiment, the set of cards was placed before the subject, the cover card was removed, and card No. 1 was placed above and to the right of the other cards. The cards in the pack were then turned successively by the observer, exposed for a definite time, and a judgment of "better" or "worse" given in terms of the standard—in this case card No. 1. After the pack had been gone through, card No. 1 was replaced, and No. 2 became the standard: and so on until each card had been compared with every other one twice, once as standard and once as comparison. A statement of the degree of confidence in the judgments given was required, "a" sure, "b" fairly sure, and "c" uncertain, being used as in the previous experiments.

Five exposure intervals were employed, 4″, 2½″, 2″, 1½″, 1″,—the same intervals previously used—the rate being regulated by a bell metronome which rang on every fourth beat. The bell which was the signal to turn the next card, controlled the intervals with a high degree of exactness, and there was little confusion as to the length of time allowed for comparison.

The five sets of specimens were known as Set 1, 2, 3, 4, 5, respectively. Each set was presented at each rate according to the following plan of rotation: Rate 1, Set 1, Rate 2, Set 2, Rate 3, Set 3, Rate 4, Set 4, Rate 5, Set 5, so that in no instance did the same set or the same rate follow successively. In only a very few cases did an observer report that he recognized a

[82]A Comparison of the Ayres and Thorndike Scales, J. Ed. Psy. 1914, 5, 525-526.

[83]Teachers Estimates of the Quality of Specimens of Handwriting. T. C. Record, Vol. 15, Nov., 1914.

TABLE XV

Showing the number of Right Cases for each Observer and for each Rate:—also, the % or right cases, and the reliability of these averages, and the differences betwen them.

		Rate 1		Rate 2		Rate 3		Rate 4		Rate 5		
Ob.	Set	R	V	R	V	R	V	R	V	R	V	Tot.
Mz	1	130	15.3	105	47.9	123	30.0	114	33.7	120	27.6	592
	2	156	10.7	175	22.1	174	21.0	168	20.3	168	20.4	841
	3	174	28.7	177	24.1	178	25.0	180	32.3	168	20.4	877
	4	168	22.7	180	27.1	192	30.0	172	24.3	177	29.4	889
	5	168	20.3	171	18.1	150	3.0	159	11.3	162	14.4	810
Tot.		796		808		817		793		795		4009
%R		75.81		76.96		77.81		75.52		75.71		76.3
Ob.	Set	R	V	R	V	R	V	R	V	R	V	Tot.
Ad	1	122	23.3	147	5.9	120	33.0	126	21.7	104	43.6	619
	2	135	10.3	169	16.1	147	6.0	153	5.3	159	11.4	763
	3	168	22.7	162	9.1	180	27.0	168	20.3	168	20.4	846
	4	132	13.3	132	10.9	141	12.0	149	1.3	144	3.7	698
	5	135	10.3	156	3.1	144	9.0	159	11.3	153	5.4	745
Tot.		692		766		732		755		728		3671
%R		65.90		72.96		69.81		71.91		69.43		69.9
Ob.	Set	R	V	R	V	R	V	R	V	R	V	Tot.
Dw	1	139	6.3	109	43.9	145	8.0	131	16.7	136	11.6	660
	2	156	10.7	146	6.9	153	.0	159	11.3	156	8.4	770
	3	129	16.3	168	15.1	161	8.0	159	11.3	168	20.4	785
	4	132	13.3	165	12.1	150	3.0	154	6.3	126	20.6	727
	5	144	1.3	150	2.9	159	6.0	153	5.3	159	11.4	765
Tot.		700		738		768		756		745		3707
%R		66.67		70.29		73.14		72.0		70.95		70.6
Ob.	Set	R	V	R	V	R	V	R	V	R	V	Tot.
Wn	1	110	35.3	103	49.9	123	30.0	116	31.7	122	25.6	574
	2	149	3.7	155	2.1	150	3.0	137	10.7	146	1.6	737
	3	151	5.7	149	3.9	150	3.0	142	5.7	118	29.6	710
	4	179	33.7	174	21.1	163	10.0	167	20.7	161	13.4	844
	5	137	8.3	150	2.9	148	5.0	113	34.7	141	6.6	689
Tot.		726		731		734		675		688		3554
%R		69.14		69.62		69.90		64.29		65.52		67.7
Ob.	Set	R	V	R	V	R	V	R	V	R	V	Tot.
Ant	1	123	22.3	125	27.9	132	21.0	115	32.7	112	35.6	607
	2	151	5.7	162	9.1	150	3.0	136	11.7	143	4.6	742
	3	156	10.7	173	20.1	179	26.0	162	14.3	162	14.4	832
	4	136	9.3	155	2.1	143	10.0	160	12.3	138	9.6	732
	5	152	6.7	166	13.1	170	1.7	142	5.7	159	11.4	789
Tot.		718		781		774		715		714		3702
%R		68.38		74.38		73.71		68.09		68.0		70.5
Sum		3632		3824		3825		3694		3690		
Av.		145.3		152.9		153.0		147.7		147.6		
%R (total)		69.18		72.84		72.86		70.36		70.29		
PE (Av)		1.11		1.39		1.17		1.24		1.27		
Diff in Avs		3.68		.02		—		2.50		2.55		
PE diffs		1.61		1.82		—		1,70		1.73		

specimen which he had seen at a some previous rate; this usually happened with a very poor or a very good specimen, or with one distinctive in some respect. I did not think that these cases were numerous or noteworthy enough to affect the general result, and therefore, no account, (other than a mention of them in the introspections) is taken of them.

PRACTICE AND FATIGUE

The use of five groups was chiefly for the purpose of preventing the necessity of presenting all the specimens at one rate successively. This precedure, if used, would very probably have introduced a memory or practice factor, and the last rate used would have enjoyed a great advantage over the others. Alternation of rates and sets should make the reliability of the general result very high; especially since the experiments extended over a considerable time, with intervals varying from a day to several weeks between, and included 26,250 comparisons in all. Rest intervals, and the relatively easy character of the experimental work ruled out the factor of fatigue.

RESULTS

Of the six men who acted as subjects in the preceding experiments, one, Sc, was unable to serve in the present experiment. He was forced through illness to leave college, and his record could not be secured. The results are, therefore, based on the judgments of five observers.

Table XV incorporates the results of the experiments. As each subject made 1050 comparisons at each rate, the sum for any one rate, eg. 3632 right cases, represents the number of right judgments in a total of 5250 trials. The average number of right cases at a given rate, means the average number of right judgments out of 210 trials, and is based on 25 measures, 5 for each observer. The % right cases for each rate, with the PE (Av.) are also given; in every instance the differences of the averages, and the PE's (diffs.) have been reckoned from Rate 3, as the largest number of right cases appeared at this rate. Diagram 8 gives, graphically, the facts of Table XV. In this diagram the rates are laid off at regular intervals on the baseline, and the accuracy records are plotted in % R-cases on the Y-axis. The total accuracy curve rises from Rate 1 to Rate 2, and remains on a level from Rate 2 to Rate 3. The accuracy falls off slightly at Rate 4, and continues

on the same reduced level to Rate 5. It will be seen that there is no difference between Rates 2 and 3, and practically none between Rates 4 and 5. However, the chances are 16 in 17 of a real increase in accuracy from Rate 1 to Rate 2, and 4 in 5 of a loss in accuracy from Rate 3 to Rate 4.

Diagram 9 shows graphically the corresponding changes in speed (reduced exposure rate) and accuracy (correct comparisons). Both factors are measured from Rate 1 as unit or 100%. The general appearance of the curves resembles closely the relation previously found between the two factors in the case of weights and lines. Starting with Rate 1, an increase in speed of 60% (i.e. decrease in exposure interval from 4″ to 2½″) caused an increase in accuracy of 5.3%, which remained constant when the speed increased 100%; an increase of 167%, and even 300%, in rate of exposure produced only a relatively slight decrease from this level, the accuracy curve still remaining 1.7% above the level (100%) of Rate 1. It appears that specimens are compared as accurately when 1″ is allowed as when 4″ are given: the speed may be increased 300% with no loss in accuracy. Speed and accuracy are again directly related up to a certain point, after which they are inversely related.

Before attempting to explain the behavior of the accuracy curve in Diagram 9, it might be well to consider the introspections of the subjects. At the conclusion of the experiment, each subject was asked to state the basis of his judgment as far as possible, and to say what effect the increased speed had on his confidence in his answers. Specific replies were requested.

INTROSPECTIONS

Mz.—I based my judgments on legibility, principally,—spacing, uniformity of lines, heaviness, etc. I prefer a medium slant over a vertical. Rate 1 allowed too much time; there was a tendency for attention to wander, and I sometimes doubted the judgment I had just given. I preferred Rates 4 and 5. At these rates I usually took a good look at the standard, and made comparisons in terms of this visual image, without troubling to look back at the standard again. I was always "a" confident, that is, I felt that I was giving the best judgment of which I was capable. I don't remember recognizing any specimen particularly.

Ad.—I judged as "better" those specimens in which the writing was regular, smooth, flowing. Rate 3 was by far the best rate; it allowed time enough for comparison without any surplus time, or feeling of being hurried. At the first rate, I believe that the long interval allowed attention to wander and permitted irrelevant details—irritation, etc., to come in. I compared the specimens directly. I recognized two samples:—one a very fine sample of slant writing, and the other a heavy vertical. I don't think that this influenced my comparisons.

Dw.—I based my judgments on legibility; formation of letters and general appearance. I prefer a slant. Rate 4 seemed to be the best interval for me, as the slow rates became very tiresome. I tried to compare each pair of specimens directly, though I often felt that my judgment was influenced somewhat by my standard of "good." So far as I know, memory of previously given comparisons did not affect my answers.

Wn.—My judgments were based on the general appearance of the handwriting, spacing, smoothness, etc. Rate 1 was too long, and I often found myself reading the sample through, rather than examining the writing. The other rates were about equally as good. Once or twice I found my judgment influenced by the resemblance of the sample to the handwriting of a friend. I also recognized the tendency to give the same degree of confidence that I had previously given. I remembered several of the specimens rather indefinitely but I don't think that it influenced my judgment.

Ant.—I preferred those specimens which were written smoothly, and regularly. I think that Rates 2 or 3 gave about the best balance, not too fast nor too slow. I compared the specimens directly; I think that I recognized a few, though I am not very certain. I don't believe that memory affected my judgment.

The explanation of the relationship of accuracy to the time of exposure in the case of handwriting is very probably similar to the explanation given for the relationship in the experiments on lines and weights. The situation in the three experiments are not esentially different, except that in the two former experiments accuracy of comparison depended primarily on native sensitivity, while in the present experiment the norm of comparison is largely the product of education and training.

In none of the experiments was there any need,—or much opportunity,—for factors other than those contained directly in the situation entering into the comparison. During the course of the experiment, the observations of the experimenter as well as the introspections of the subjects indicated that Rate 1 was too slow. Comparatively a large part of the interval was unused, judgments were often given very quickly, and during the remainder of the interval the observer merely waited for the bell to signal the next comparison. Slight irritation, lapses of attention, boredom, were often in evidence. Rates 2, 3, and even 4 seemed to be better balanced; i.e. they allowed time for the cards to be turned and judgment to be given in a regular and rhythmic fashion. Rate 5, while a bit strenuous both for the observer and the recorder, still allowed time enough for the observer to register his comparison. I found it impossible for the observer to vocalize, or the recorder to note down comparisons, when less than 1″ was allowed. It might seem that the manipulation, eg. turning of the cards, was the main reason for the loss in accuracy at Rates 4 and 5, but the observers became so skillful in turning the cards, and there were so few interruptions due to a loss of rhythm, that I do not believe that this factor played any considerable part in determining the accuracy. Also, the lowest accuracy record was at Rate 1.

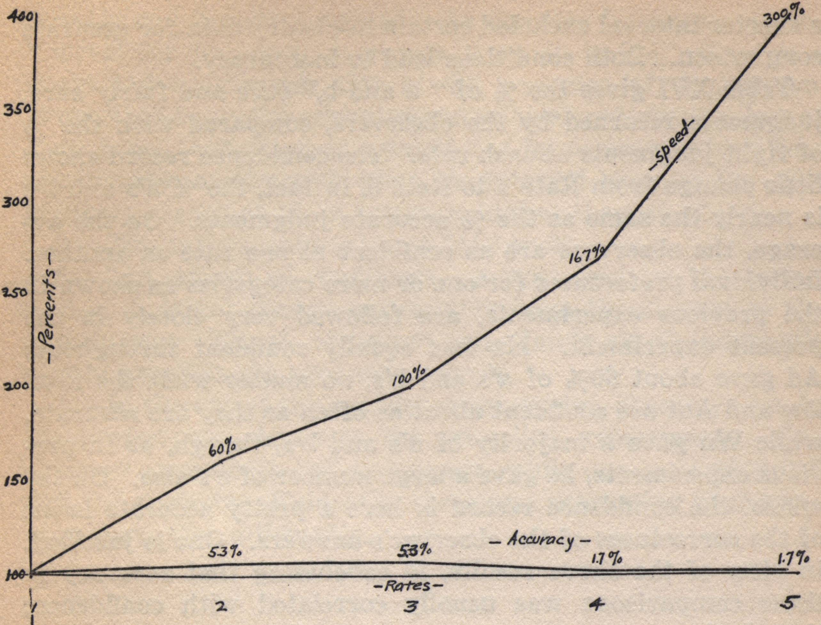
Rates 2 and 3 insofar as they deserve to be called 'optimal" derive their superiority from the fact that they gave just time enough for the factors determining the judgment to mature, more specifically, for the observer to perceive both stand-

TABLE XVI

Showing the Per Cent of "a" and "b" Judgments given by each Observer at each rate, compared with the Per Cent of right cases at same rate. Five Observers,—5250 comparisons by each.

	Rate 1 Per Ct.		Rate 2 Per Ct.		Rate 3 Per Ct.		Rate 4 Per Ct.		Rate 5 Per Ct.		Totals Per Ct.	
Obs.	a b	R	a b	R	a b	R	a b	R	a b	R	a b	R
Mz.	100	75.8	100	77.0	100	77.8	100	75.5	100	75.7	100	76.3
Ad.	60	66.0	56.2	73.0	61.4	69.7	61.8	72.0	63.3	69.4	60.6	69.9
Dw.	80	66.7	79	70.3	66.7	73.1	75.2	72.0	80.5	71.0	76.0	70.6
Ant.	71.8	68.4	74.3	74.4	73.8	73.7	60.0	68.0	73.8	68.0	70.6	70.5
Wn.	64	69.2	59.5	69.6	59.0	70.0	55.2	64.2	59.5	65.5	59.4	67.7
Per Ct. R	74.7	69.2	73.8	72.8	72.2	72.9	70.4	70.4	75.4	70.3	73.3	71.0

ard and comparison clearly enough and long enough to isolate those details, shape, legibility, appearance or what not through which the comparison was made. A longer interval, therefore, must have allowed irrelevant facts to slip in; while



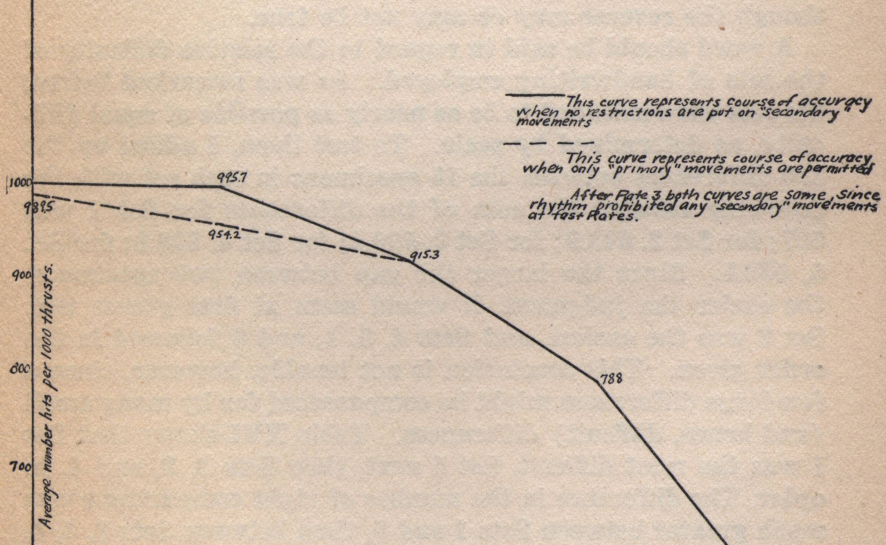


Diagram 9.—Showing the corresponding changes in speed and accuracy measured from Rate 1 as 100.
Diagram 10.—Showing the number of hits per 100 thrusts at each rate.

a shorter interval excluded certain necessary data for accurate comparison. Both conditions lead to inaccuracy.

Table XVI gives the % of " a and b," sure and fairly sure, judgments returned by the observers, compared with the % of right judgments at each rate. The confidence record shows little change from Rate 1 to Rate 5, in fact, the % a's and b's is nearly the same as the % accurate judgments. On the average, the observers are as confident at one rate as another. Individual preferences for one or more categories as shown in the previous experiments, are followed very closely in the present experiment. Mz was equally confident throughout; Ad gave about 60% of a's and b's, no matter what the rate. Dw and Ant are confident about as often as they are accurate, while Wn gave a majority of a's and b's, though, as in previous experiments, he gave a large number of c's also. On the whole, the confidence record is here a pretty accurate index of the correctness of the observer's answers. One is justified, in view of the above results, in concluding that accuracy in these comparisons was usually correlated with confidence; though the reverse may or may not be true.

A word should be said in regard to the relative difficulty of the sets of handwriting employed. As was remarked before, the sets were intended to be as nearly as possible of equal difficulty, as determined by scale. To test them, I added up the 210 differences between the 15 specimens in each set with the following results: the sum of the differences for Set 1 was 537; for Set 2, 673.9; for Set 3, 506.4; for Set 4, 626.3; for Set 5, 588.5. Since the larger the gap between two specimens, the easier the judgment, it would seem at first glance that Set 2 was the easiest, and Sets 4, 5, 1, and 3 followed in the order given. This conclusion is not tenable, however, since a few large differences might be compensated for by many small (and hence, difficult) differences. Table XVI shows that Set 1 was the most difficult, Set 5 next, then Sets 3, 2, and 4, in order. The difference in the number of right comparisons was much greater between Sets 1 and 5, than between Sets 2, 3, 4, or 5.

CONCLUSIONS

The conclusions to be drawn from this experiment as to the relation of speed and accuracy are as follows:

1.—In the present experiment, speed and accuracy are both

directly and inversely related. As the rate increases, eg. the interval for judgment decreases, from 4″ to 2½″, there is a slight but appreciable rise in the accuracy of comparison. From 2½″ to 2″ the accuracy record does not change, but at Rate 4, eg. 1½″, there is a small loss in accuracy which does not increase or diminish when the interval becomes 1″. The accuracy record at 1″, is however, higher than at 4″.

2.—The optimal interval is at 2½″ or 2″.

3.—The degree of confidence, as expressed by the terms, *a, b, c,* does not change appreciably from the slowest to the fastest rate. The % of "sure" and "fairly sure" judgments closely parallels the accuracy records.

4.—In the use of the confidence categories, observers retain the preferences shown in the preceding experiments. One observer gave 100% "a" judgments, while one gave 60% "a" and "b" answers. Evidently, the terms expressing confidence are interpreted differently.

SECTION III

COORDINATION EXPERIMENTS.

1. Thrusting Experiment. 2. Maze Tracing Experiments.

PROBLEM

These two experiments were planned for the purpose of tracing the course of accuracy for a fairly simple series of muscular movements when the speed with which the movements are made is varied in a definite and regular manner. In both experiments the speed was the variable factor, and the accuracy for each "Rate" was measured in terms of "misses" or "touches." No judgment is required, the task being purely one of voluntary muscular coordination in which the reagent simply makes the prescribed movements at the dictated rates.

APPARATUS

The Three Hole Aiming Test, which was used for the Thrusting Experiment, consists of a wooden board on which is fastened a wooden triangle inclined to the board at an angle of 45 degrees. The triangle, which is equilateral, has a brass-lined hole in each angle, and the subject's task is to thrust a metal rod or stylus into the three holes alternately. The stylus is just large enough to fit into the holes easily. Each successful thrust into a hole is recorded on a clock which is in electrical connection with the brass-lined holes and the metal stylus. This apparatus was designed by Prof. Woodworth and used by him at the World's Fair in 1904. It has been used by Stecher[84] and Hollingworth[85] as a test of efficiency in motor co-ordination under different physical or physiological conditions. As a measure of voluntary muscular control, this test is very useful, as it requires coordination of a group of muscles under the guidance of visual impression, i.e. accurate co-ordination of eye and arm in the performance of a definite task.

The ease with which the speed can be controlled (i.e. rate of thrusting) and the accuracy (hits) measured, recommend-

[84]Effects of Humidity on General Eciency, Archives of Psy. *38*, 1916.

[85]The Influence of Caffeine on Mental and Motor Efficiency, Archives of Psy. *22*, 1911.

ed this apparatus as useful in a study of the speed-accuracy relation. It is true that there is no way of measuring the amount of error or "miss" except in lengthened time, but for the purposes of this experiment it seemed sufficient simply to take all errors as of equal value. This procedure does not, of course, take into account the amount of "miss," but the range for misses is so small that I did not think it worth considering.

The Three Hole Aiming Test is essentially a target test, in which a rapid thrusting movement is required. As a test of a motor coordination of a slightly different kind I have used a maze test in which the movement is a continuous one—more like a writing movement—and in which steadiness is an important factor. The Coordination Test (Johnson-Dunlap) of the Johns Hopkins Series was used, since this test is prepared for tracing regulated by a metronome. Tracing is done from right to left, so that the pathway ahead may not be hidden by the hand. One stroke is made to each beat of the metronome, and accuracy is measured by the number of times the traced line touches the guide lines. This particular maze test consists of 6 sections in duplicate, and as each section requires 17 separate movements, there are 102 movements made in tracing one blank.

PROCEDURE

The procedure followed in the thrusting experiment was very simple. With the subject seated before the board, the metronome was started and the subject was instructed to thrust the stylus into the three holes in order, one thrust for each beat. The first thrust was in the lower left hand hole, and the order of thrusting was counter-clockwise. Five different rates of thrusting were used, with the metronome set to beat 60, 96, 120, 160, 240 (approx.) times per minute. One thrust, therefore, occupied 1″, ⅝″, ½″, ⅜″, or ¾″. One hundred thrusts at any one rate constituted one trial. To insure one thrust for each beat of the metronome, and also 100 and no more thrusts—the experimenter counted in time with the metronome, breaking the electrical circuit on the 100th count. At the end of each trial, the number of hits were read from the clock.

Before beginning a trial at a changed rate, a preliminary series of thrusts was taken in order to accustom the subject

to the new rhythm and thus avoid any sudden "jump" in the accuracy of the succeeding trials due to poor adjustment in the first. This plan was also intended to cut down the interference effect which might arise in the shift from one rate to another. In spite of these "adjustment" series, the practice effect was pronouncedly present at all rates as may be seen by referring to the succeeding trials for any one rate. The trials were taken according to a regular plan, eg. 100 thrusts at Rate 1, 100 at Rate 3, 100 at Rate 5, etc. This was done in order to spread the practice effect equally, and not give any one rate the advantage in regard to practice. Two or three minutes rest were allowed between trials, and never more than 1000 thrusts were taken at one sitting;—hence fatigue was not considered as a factor in the experiment.

In the tracing experiment, the subject was instructed to start at the cross marking the entrance of the upper right hand pathway, and make one move for each beat of the metronome. A fountain pen was used for the tracing, as a pencil changes the width of the line between the start-point and the finish. After tracing the first pathway, the subject returns to the pathway immediately below, pausing for a beat or two in order to catch the rhythm. This interval between pathways varied slightly according to the rate,—usually occupying a second or two. No attempt was made to control it, other than to keep it from becoming too long or too short. Ten sheets were traced by each subject at each rate. Since each sheet required 102 movements, as stated before, 1020 movements at each rate or 5100 movements in all were made by each subject.

The time intervals used for tracing were the same as those used in the thrusting experiment. With the metronome set at 60, 96, 120, 160, 240, each movement occupied 1″, ⅝″, ½″, ⅜″, ¾″. A regular order of trials was followed:—no two sheets were traced successively at the same rate. This plan, as in the thrusting experiment, was designed to eliminate a concentration of practice effect at one rate. The whole experiment did not occupy, for one subject, more than two hours; and frequent rest intervals are believed to have ruled out fatigue as a factor.

1. *Thrusting Experiment*

RESULTS

In performing the thrusting experiments, the data for which are to be found in Table XVII, the subjects were given no specific instructions as to the method to be used in making the thrusts. They were simply told to keep the rhythm,—make one thrust to every beat of the metronome. At Rate 1, the slowness of the rhythm permitted a subject to correct an inaccurate thrust or "primary movement" by a later small "secondary movement"; for example, if the stylus missed the hole by a small margin, it could be quickly pushed in and a hit recorded without losing the rhythm. This use of a "secondary movement" was noticeable, though to a somewhat lesser extent at Rate 2 also. At the faster rates, 3, 4, 5, the speed of the thrusting movement precluded any later adjustments, without sacrificing the rhythm, and, in consequence, the accuracy depended entirely on the initial thrust or "primary movement." In order to make the accuracy records comparable for all rates, I conducted a second set of experiments at Rates 1 and 2 only, in which the subject was instructed NOT to make any corrections of an inaccurate thrust no matter how much time he had for doing so. In a sense, the first method is the most logical one, since, from a practical standpoint, the slower rates should be given the advantage which they offer of later adjustments,—if for no other reason than as a compensation for their slowness. In presenting the results of the experi-

TABLE XVII

Records (errors) 6 Subjects:—5 Rates, 30,000 Thrusts.

An error is defined as a "miss." Later adjustments, eg. in case of a miss, not prohibited;—allowed as long as Subject did not lose rhythm. These later adjustments immediately after a thrust were used generally at Rates 1 and 2, but speed of thrusts did not permit them at Rates 3, 4, or 5.

Rate 1 Met. 60 100 thrusts in 100″

Trials	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Errors													
Mz.	0	0	0	0	0	0	0	0	0	0	0	1000	–
Ad	0	0	0	0	0	0	0	0	0	0	0	1000	–
Dw	0	0	0	0	0	0	0	0	0	0	0	1000	–
Wn	0	0	0	0	0	0	0	0	0	0	0	1000	–
Ant	0	0	0	0	0	0	0	0	0	0	0	1000	–
Sc	0	0	0	0	0	0	0	0	0	0	0	1000	–
Total	0	0	0	0	0	0	0	0	0	0	0	6000	–
Av.			0				0					1000	
Acc%			100				100					100%	–

Rate 2 Met. 96 100 thrusts in 62.5″

Trials	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Errors													
Mz.	4	2	0	0	0	0	0	0	0	0	6	994	1.7
Ad	3	2	0	0	1	0	0	0	0	0	6	994	1.7
Dw	2	2	0	0	0	0	0	0	0	0	4	996	.3
Wn	0	0	0	0	0	0	0	0	0	0	0	1000	4.3
Ant	5	0	1	2	0	0	0	0	0	0	8	992	3.7
Sc	1	0	1	0	0	0	0	0	0	0	2	998	2.3
Total	15	6	2	2	1	0	0	0	0	0	26	5974	14.0
Av.	2.5	1.0	.3	.3	.2	0	0	0	0	0	4.3	995.7	
A.D.	1.1	.5	.2	.3	.1	0	0	0	0	0	1.6	2.3	
Acc%			99.1				100					99.6%	

Rate 3 Met. 120 100 thrusts 50″

Trials	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Errors													
Mz	20	11	8	5	4	6	4	3	4	6	71	929	13.7
Ad	24	22	19	7	8	12	9	10	9	7	127	873	42.3
Dw	22	21	15	4	2	2	1	2	2	2	73	927	11.7
Wn	6	6	3	3	3	4	4	4	3	1	37	963	47.7
Ant	18	16	12	15	18	20	10	15	9	10	143	857	58.3
Sc	12	8	4	10	3	1	8	3	3	5	57	943	27.7
Total	102	84	61	44	38	45	36	37	30	31	508	5492	201.4
Av	17	14	10.2	7.3	6.3	7.5	6.0	6.2	5	5.2	84.7	915.3	
A.D	5.3	5.7	5	3.4	4.4	6.2	3	4.2	2.7	2.5	33.4	33.6	
Acc%			89.0					94.0				91.5%	

Rate 4 Met. 160 100 thrusts 37.5″

Trials	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Errors													
Mz	30	35	23	19	18	19	25	23	11	22	225	775	3.0
Ad	24	28	25	27	24	18	27	19	22	28	242	758	30.0
Dw	49	45	29	31	16	14	20	23	18	16	261	739	49.0
Wn	15	15	18	19	16	15	11	11	11	11	142	858	70.0
Ant	30	36	27	31	20	22	15	20	19	18	238	762	26.0
Sc	28	23	20	19	11	7	23	15	9	9	164	836	48.0
Total	176	182	142	146	105	95	121	111	90	104	1272	4728	226.0
Av.	29.3	30.3	23.7	24.3	17.5	15.8	20.2	18.5	15	17.3	212	788.0	
A.D.	7.0	8.3	3.3	5.3	3.2	4.0	4.5	3.7	4.7	5.0	35.3	37.7	
Acc%			75%					82.6%				78.8%	

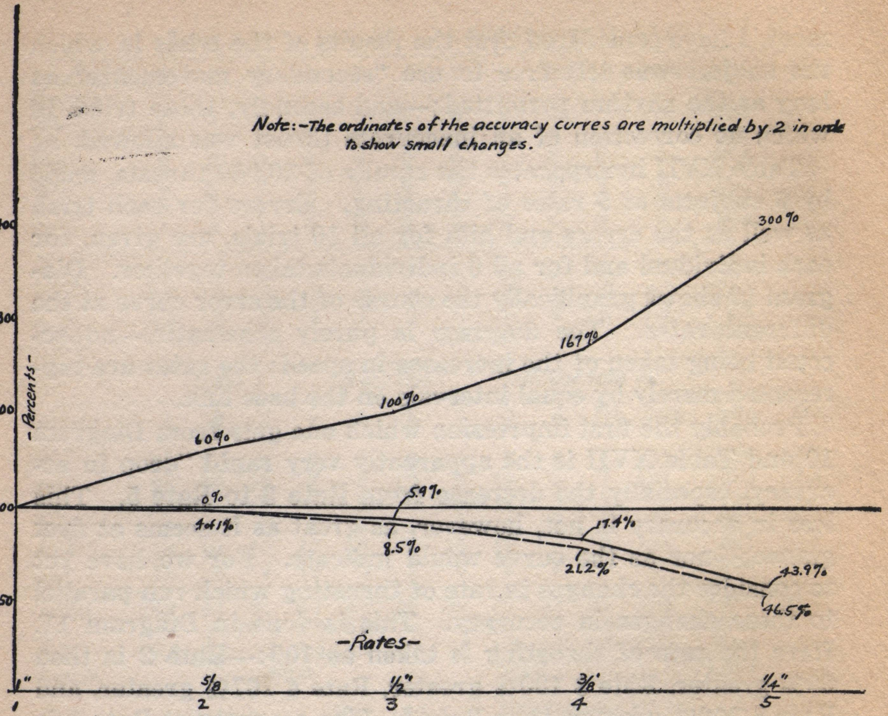
Rate 5 Met. 240 100 thrusts 25″

Trials	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Errors													
Mz	50	46	59	49	53	42	46	51	51	50	497	503	31.7
Ad	58	53	56	47	58	44	43	49	42	40	500	500	34.7
Dw	67	60	53	46	40	43	43	39	37	35	463	537	2.3
Wn	44	42	45	46	40	37	42	33	46	45	420	580	45.3
Ant	47	53	51	42	47	50	43	49	45	40	467	533	1.7
Sc	53	44	48	39	40	54	46	42	39	40	445	555	20.3
Total	319	298	312	269	278	270	263	263	260	260	2792	3208	136.0
Av.	53.2	49.7	52	44.8	46.3	45	44	44	43.3	43.3	465.3	534.7	
A.D.	6.0	5.7	4	2.8	6.3	4.7	1.5	6	4.0	5.0		22.7	
Acc%			50.8				56.1					53.5	

ment, I have considered first the results of the trials in which the subject was left free to use "secondary movements" as long as the rhythm permitted;—and secondly, those trials in which no correction of an inaccurate thrust was allowed.

Table XVII incorporates the results of 30,000 thrusts, made by 6 subjects at 5 rates of thrusting. Errors for each trial, as well as the errors and hits for all 10 trials, are given, for each individual and for all 6 individuals taken together. Diagram 10 shows graphically the course of the error curve at the different rates. The diagram is purely schematic,—no account being taken of the increases in speed; the rates are represented merely by equal intervals on the base line.

Probably the first impression which one gets from Diagram 10 and Table XVII is the apparently very rapid "drop in accuracy, especially the decrease from Rate 3 to Rate 5. This loss in accuracy is not, however, as great as it seems at first glance;—nor as the curve would indicate. For we have yet to consider the changes in rate of thrusting which run parallel to these changes in accuracy. This is done in Diagram 11. Here the rate of thrusting is taken as 100:—Rate 2 is then 60% greater, Rate 3 100% greater, Rate 4 167% greater, and Rate 5 300% greater, than Rate 1. The accuracy at Rate 1 is also taken as 100%. The loss in accuracy at Rate 2 is then only .4 of 1% from Rate 1; at Rate 3 the loss is 8.4%, at Rate 4, 21.2%, and at Rate 5, 46.5%. Thus it is apparent, that, while Speed and Accuracy are inversely related, the decrease in accuracy at a given rate does not compare with the increase in speed at the same rate. In fact, the loss in accuracy as far as Rate 3 is negligible, when misses are considered in relation to hits. The representation of changes in accuracy by errors alone has led to many false conclusions as to diminution in efficiency due to fatigue, changes in conditions, changes in procedure, etc. Thorndike[86] after citing the results of Sikorski, who in testing the same children before school and after school in writing from dictation, found the average per cent of wrong letters to be 33⅓% greater in the late tests, says: "I trust that the reader is not so unsophisticated as to assume that the above figures, even if taken at face value, show an efficiency before school of 1⅓ times that existing after school. They as truly mean that, since about 99.3% of the letters were correct in the morning and about 99% after school, the efficiency before school was 1.0033 times that existing after



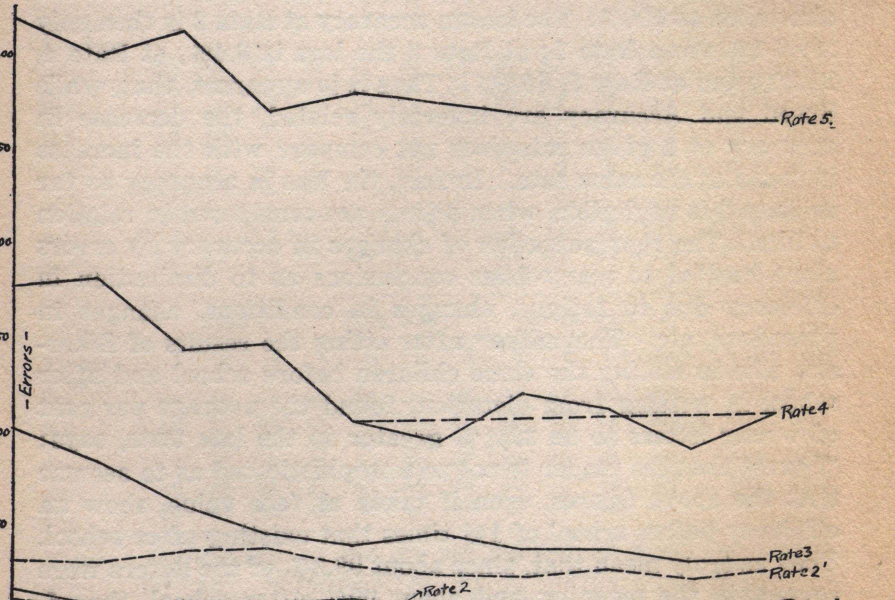


Diagram 11.—Showing the changes in the accuracy of thrusting corresponding to the changes in rate of thrusting. Both speed and accuracy measured from Rate 1 as 100. The solid line represents the accuracy records from the second half of the experiment with practice eliminated. .The dotted line shows the course of accuracy for the whole experiment.

Diagram 12.—Practice curves for Rates 2, 3, 4, 5, from trial 1 to 10. Dotted lines show the practice effect when no "secondary" movements were allowed: eg.—Rates 1 and 2.

school." In thus minimizing the loss in accuracy, in relation to the increase in speed, it must not be overlooked that we could hardly expect the accuracy to vary equally with the speed. In the present experiment, for instance, accuracy can only fall from 100% to 0, while the speed can increase almost indefinitely.

Table XVII contains another fact, just as obvious as the speed-accuracy relation, and much more real on the face of it: namely, the very evident improvement shown by all the subjects, no matter what the rate. This improvement is largely attributable to practice. Diagram 12 shows the changes in accuracy (in terms of errors) for each trial from 1 to 10. The practice curves for each rate, with the exception of Rate 1, are plotted separately. At Rate 2 improvement ends at trial 3, the errors drop out completely at trial 6, and do not appear again; only trials 1 and 2 give evidence of appreciable error and some of these errors are almost certainly due to the awkwardness and lack of adjustment, uncertainty, etc., nearly always present at the beginning of any experiment. In spite of the preliminary series given with the express intention of eliminating just such errors, some subjects are slower than others in "warming up," and some become more easily confused and "thrown off the track." Hollingworth[87] in speaking of this test (3 Hole) remarks that skill in the test varies for quite unaccountable reasons, and that much seemed to depend on beginning luckily and striking a favorable rhythm. The fluctuations in accuracy for thrusts at Rate 3, are very slight after trial 5; the flatness of the curve from this point on indicating that practice has practically spent itself, though it is very clearly present in the first four trials. Rate 4 shows rather erratic changes in accuracy. The decrease in errors gives evidence of practice during the first 5 trials; but from trial 5 to trial 10, the accuracy, for some unknown reason, fluctuates up and down, though the changes are not so great, nor so evidently in the one direction of improvement, as in the first 5 trials. A straight line drawn from a point representing trial 5 to the point representing trial 10, by balancing the factors that make for accuracy, i.e. practice, adaptation, etc., vs. those that make for inaccuracy, eg. speed, loss of rhythm, etc., would probably give a fairer picture of the accuracy curve in this region. The changes in

[86]Ed. Psy. Vol. III, p. 81 ff.

the curve for Rate 5 are practically all in the first 5 or 6 trials; after trial 5 the flatness of the curve indicates that no further significant changes from practice are to be expected.

The trend of the curves in Diagram 12 seems to warrant the assumption that practice is negligible as a factor in improving accuracy after the first five trials. Accordingly, I have divided the thrusts at each rate into two groups (Table XVII) the first comprising trials 1 to 5, and the second trials 6 to 10. Each group represents, therefore, the records of 3,000 thrusts—the second, with practice eliminated.

The accuracy at each rate when corrected for practice, is represented in Diagram 11. It is worthy of note, as showing the effect of practice, that the decrease in accuracy for Rates 2, 3, 4, 5, measured from Rate 1 as 100%, is at every rate less than when all the trials are taken into account. Except at Rates 1 and 2, the elimination of practice means about 3% increase in the accuracy record at each rate.

In examining the factors that enter into an accurate thrust, I have used the terms, "primary movement" and "secondary movement." These terms are used, as was said before, to represent the initial thrusting movement, and the later small movements which are necessary for a hit when the subject's aim is inaccurate. It was evident to the experimenter that a large share of the credit for the high accuracy at the first two rates must be given to this second factor, which at Rates 3, 4, 5, the speed of the rhythm ruled out. A hit at these rates depended almost entirely on the accuracy of the initial aim.

This conclusion is substantiated by the second series of experiments, and also by the more detailed analysis of a voluntary movement made by Woodworth.[88] In separating out the factors involved in a voluntary movement, Woodworth distinguishes between two chief influences, the "initial adjustment," and the "current control." The operation of these factors can best be shown by an example. In drawing lines on a revolving drum, with the requirement that each line equal that which immediately precedes it, the "initial adjustment" or preliminary adjustment, of the movement is to be distinguished from the "current control" of the movement

[87]The influence of Caffeine on Mental and Motor Efficiency, Archiv. of Psych. 22, p. 49.

[88]Op. cit. 27-62.

process, eg. the drawing of the line itself, and the fine adjustments at the end of the line. An increase in the speed of the movement with a consequent decrease in the interval between successive movements affects these two factors differently. The shortened interval aids initial adjustment by setting up a "momentum of uniformity," eg. making the movements regular, rhythmic, and automatic, while the increased speed works for inaccuracy by making impossible

TABLE XVIII

6,000 thrusts at two Rates 1 and 2: 6 Subjects: Records in terms of "misses." Subjects were instructed not to use secondary movements. If a thrust missed a hole it was counted a miss, no correction being allowed.

Rate 1

Trial	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Error													
Mz	2	2	1	0	0	1	2	1	1	0	10	990	.5
Ad	1	2	1	4	5	2	1	3	1	2	22	978	11.5
Dw	2	0	2	1	3	0	1	0	2	1	12	988	1.5
Wn	0	0	0	0	0	0	0	0	0	0	0	1000	10.5
Ant	4	1	2	1	2	0	1	2	0	3	16	984	5.5
Sc	1	0	1	0	0	1	0	0	0	0	3	997	7.5
Total	10	5	7	6	10	4	5	6	4	6	63	5937	37.0
Av.	1.7	.8	1.2	1	1.7	.7	.8	1	.7	1	10.5	989.5	
Ad.	.7	.5	.4	.5	.8	.3	.3	.5	.3	.5		6.2	
%acc			99%					99%				99%	

Rate 2

Trial	1	2	3	4	5	6	7	8	9	10	sum	hits	dev.
Error													
Mz	5	6	5	3	7	4	2	3	1	2	38	962	7.8
Ad	6	5	8	10	4	3	6	5	4	3	54	946	8.2
Dw	5	8	7	5	2	6	3	5	5	6	52	948	6.2
Wn	4	2	5	4	5	2	4	4	4	5	39	961	6.8
Ant	7	4	4	8	6	5	3	6	5	5	53	947	7.2
Sc	3	4	5	6	3	4	5	2	3	4	39	961	6.8
Total	30	29	34	36	27	24	23	25	22	25	275	5725	43.0
Av.	5	4.8	5.7	6	4.5	4	3.8	4.2	3.7	4.2		954.2	
Ad.	1	1.5	1.2	2	1.5	1	1.2	1.2	1.1	1.1		7.2	
%acc				94.8					96.0			95.4	

exact and final adjustments. A movement, therefore, which depends for its accuracy largely or entirely on its initial adjustment should, according to this view, rapidly become inaccurate with increased speed IF the "initial adjustment" must act in "opposition to the momentum of uniformity." The decreased interval does no good, and the speed does harm. Such a movement Woodworth illustrates by his "three target test" (op. cit. p. 49) in which the subject thrust with a pencil

alternately at three dots arranged in the form of an equilateral triangle. To quote him: "Here each initial adjustment is a repetition not of the last, but of the third before. Between, two movements of quite different direction have been made. And anything like automaticity is excluded by the angular character of the whole movement. The natural tendency to cut corners is not a help but a hindrance to accuracy. Thus the 'momentum of uniformity,' if operative at all, is so only to a slight extent. The result is that, in proportion as speed interferes with 'current control,' the accuracy is lost. There is no flattening out of the curve at the higher rates, but the error increases by great jumps, making the last part of the curve the steepest." This discussion, especially as it relates to the two factors in voluntary movement, and to the rapid loss in accuracy at the fast rates, is directly applicable to the results from the three hole apparatus.

In Table XVIII are the results of 6,000 thrusts at Rates 1 and 2, in which "secondary movements" were ruled out by instructing each subject not to correct a miss, but to go directly to the next hole, the rhythm being kept the while. By this change in procedure, the accuracy at both rates is reduced, though Rate 1 is still more accurate than Rate 2, and Rate 2 more accurate than Rate 3. The practice curves for both rates, (Diagram 12) show the same flattened appearance from trial 6 on, previously noted in the curves for the other rates. The decrease in accuracy, though still small, is much greater than the decrease for the same rates in the previous experiments. Rate 1 shows a loss of 1% in accuracy, with or without the practice effect, and Rate 2, a loss of 4.6% without, and 4% with correction for practice.

The question of the optimum rate for thrusting remains to be considered. Taking the experiment as a whole, it is clear that no matter whether the subject is left free to correct his inaccurate thrusts, or is instructed not to correct them, Rate 1, as far as errors go, gives the greatest accuracy. Rate 2 is next, and the other rates follow in order, so that we can generalize by saying that speed and accuracy are inversely related in a regular manner. We could hardly stop here, however, for the relation of increase in speed to decrease in accuracy, as well as the practice effect, have not been taken into consideration. With practice eliminated, the accuracy curve (Diagram 11) shows Rate 2 as equal to Rate 1, while the relatively slight

decrease in accuracy at Rate 3 (5.9%) and even the decrease at Rate 4 (17.3%) would certainly give these rates a claim in many sorts of everyday use of a co-ordinated movement like the one here illustrated. In some kinds of work, an employer might very probably prefer an operator of a machine who could make a movement in ½″ with 6% errors in 6,000 trials to one who required twice as long to make the same movement, even if the latter were always accurate. With practice eliminated, a consideration of the time factor, therefore, would certainly shift the optimum rate from Rate 1 to Rate 2, and in some cases to Rate 3. Rate 5 is too inaccurate to be considered, as the chances that a subject will "hit" rather than "miss" are only 1 in 2—a subject hits about as often as he misses. This reduction of the accuracy to a "chance" basis obviates the necessity of attempting a faster rate.

Reference to Table XVII, shows that the six subjects tend to "bunch" more closely at Rates 1 and 5, and to "spread out," become more variable, at the intermediate rates. This is most probably due to the fact that they were equally accurate at Rate 1, and equally inaccurate at Rate 5, the middle rates tending to bring out individual differences. It is interesting to note that the A. D. does not vary much with successive trials—though practice reduces the scores of all the subjects, they hold very closely to their relative positions.

Individual differences in the accuracy of thrusting appear at Rate 1, and may be found throughout the experiment. If we rank the subjects in order for accuracy at each rate, we get the following table.

	R–1	R–1′	R–2	R–2′	R–3	R–4	R–5	Sum	Ave.	Rel. Pos.
Mz.	–	3	4.5	1	3	3	5	19.5	3.25	3
Ad.	–	6	4.5	6	5	5	6	32.5	5.42	6
Dw.	–	4	3	4	4	6	3	24.0	4.00	4
Wn.	–	1	1	2.5	1	1	1	7.5	1.25	1
Ant.	–	5	6	5	6	4	4	30.0	5.00	5
Sc.	–	2	2	2.5	2	2	2	12.5	2.19	2

Note: The (′) at Rates 1 and 2 refers to the second series.

Wn and Sc are the most accurate throughout, and Ant and Ad the least accurate. There is very little shifting of relative position, a subject evidently "hitting his stride" early, and holding it. Table XVII shows that the subjects who are least

accurate, are usually inaccurate in the first trials at the different rates; these trials have too many errors in comparison with successive trials. Observation of the thrusting of the different men suggests that some men have a "knack" for simple co-ordinated movements which others do not possess, either through lack of fine muscular control, nervousness, susceptibility to becoming easily confused, lack of patience, etc. In a long series of thrusts, with the rhythm fixed, there is little chance for luck to play much of a role, and, therefore, the subject's record is a pretty good indication of his ability in the function tested.

CONCLUSIONS

1.—Speed and accuracy in a comparatively simple co-ordinated movement, such as the one here used, are inversely related—as the speed increases the accuracy decreases.

2.—In comparison with the increase in speed the decrease in accuracy is slight, so that if time is considered as a factor, the optimum rate for both speed and accuracy, with practice eliminated, would lie at Rate 2, and in some cases at Rate 3.

3.—Practice was markedly operative in the experiment during the first 3,000 thrusts, but in the last 3,000 thrusts, if present at all it was very slight.

4.—The conclusions stated so far hold, whether the subjects are instructed to rely solely on accuracy of aim or are permitted to use secondary correcting movements.

5.—In this experiment, those men who rank high at any given rate, tend to hold their relative positions at all other rates.

2. Maze Tracing Experiment

RESULTS

In the tracing movement as required in this experiment, there was no distinction, such as that made in the previous experiment, between "primary" and "secondary" movements. No matter what the rate, there was always plenty of time for initial adjustment—the subject was given time enough to place his pen on the cross at the beginning of the pathway, and catch the rhythm before beginning the actual tracing.

This experiment requires a precise co-ordination of the muscles of the arm, hand, and fingers with the visual impression; accuracy depending, more specifically, on the skill with which the pen point can be moved along between the two guide lines. There is very little difference between the mechanics of the tracing and the thrusting movements, as here used; both are comparatively short and intermittent, and both require the same muscular and visual co-ordination. In tracing, however, the movement is shorter and made with less effort—it is also more continuous in the same general direction, less angular, than the thrusting movement.

Table XIX gives the results of the experiment in detailed form, and is arranged after the plan already described in the Thrusting Experiment. One difficulty not met in the former experiment arises when we come to estimate the relative accuracy at the different rates. In making thrusts at a bull's eye, each thrust is either a hit or a miss, and accuracy is easily figured in % of hits in a total number of thrusts. In tracing, on the contrary, the number of touches in a given movement is a variable quantity, and may range between fairly wide limits. Accuracy, therefore, can only be measured in terms of errors divided by total number of movements. This is what has been done, though it is a question whether we can assume that one touch is equal to another as a measure of failure to co-ordinate. Any weighting system, however, involves too many sources of error, variable factors, etc., and

TABLE XIX

Records in terms of touches: 6 Subjects: 5 Rates: 1020 separate movements at each rate. Accuracy is reckoned 100%—(errors÷total number of movements). Total number of movements is divided into 2 groups; in second group pratice is eliminated.

Rate 1 Met. 60

Trials	1	2	3	4	5	6	7	8	9	10	sum	dev.
Errors—i. e. touches												
Mz	3	3	0	0	1	2	2	0	1	0	12	6
Ad	1	3	2	7	3	4	6	3	2	2	33	15
Dw	1	0	1	0	2	1	0	0	0	0	5	13
Wn	4	0	0	0	0	0	0	0	0	0	4	14
Ant	6	5	1	0	4	5	5	5	7	6	44	26
Sc	2	1	1	1	0	3	2	0	0	0	10	8
Total	17	12	5	8	10	15	15	8	10	8	108	82
Av.	2.8	2	.8	1.3	1.7	2.5	2.5	1.3	1.7	1.3	18	
A.D.	1.5	1.0	.3	1.0	.8	1.1	1.2	.9	1.0	.9	13.7	
Errors			52					56				
%Acc								98.17			98.24	

Rate 2 Met. 96

Trials	1	2	3	4	5	6	7	8	9	10	sum	dev.
Errors—touches												
Mz	8	5	2	2	1	0	1	2	1	0	22	26.8
Ad	10	9	10	11	11	9	8	9	4	0	81	32.2
Dw	6	5	7	0	2	1	0	2	0	1	24	24.8
Wn	9	4	3	1	1	2	0	2	2	1	24	23.8
Ant	14	10	11	8	4	9	7	6	12	9	90	41.2
Sc	10	10	7	5	2	7	6	2	1	1	51	2.2
Total	57	43	40	27	21	28	22	23	20	12	293	153.0
Av.	9.5	7.2	6.7	4.5	3.5	4.7	3.7	3.8	3.3	2	48.8	
A.D.	1.7	2.5	2.8	2.7	2.7	2.9	2.1	2.4	2.5	1.7	25.5	
Errors			188					105				
%Acc								96.85			95.21	

Rate 3 Met. 120

Errors—touches												
Trials	1	2	3	4	5	6	7	8	9	10	sum	dev.
Mz	10	9	11	6	5	3	2	7	8	5	66	19.5
Ad	5	15	9	11	10	10	9	8	9	6	92	6.5
Dw	16	14	14	14	16	9	8	4	6	8	108	22.5
Wn	13	8	10	6	8	6	6	13	10	7	87	1.5
Ant	11	19	14	14	10	9	6	7	5	7	102	16.5
Sc	18	9	5	6	2	7	4	3	3	1	58	27.5
Total	73	74	63	57	51	44	35	42	41	33	513	94.0
Av.	12.2	12.3	10.5	9.5	8.5	7.3	5.8	7.0	6.8	5.5	85.5	
A.D.	3.5	3.7	2.5	3.5	3.5	2.0	1.6	2.3	2.2	1.7	15.7	
Errors			318					195				
%Acc								93.63			91.62	

Rate 4 Met. 160

Trials	1	2	3	4	5	6	7	8	9	10	sum	dev.
Errors—touches												
Mz.	23	20	10	12	10	13	8	7	8	7	118	46.8
Ad	21	23	19	14	6	11	11	21	13	19	158	6.8
Dw	22	14	20	18	18	18	15	21	18	16	180	15.2
Wn	20	25	12	13	8	7	10	9	10	7	121	43.8
Ant	43	41	31	25	23	26	25	23	11	18	226	101.2
Sc	20	15	20	17	7	12	17	16	11	11	146	18.8
Total	149	138	112	99	72	87	86	97	71	78	989	232.6
Av.	24.8	23	18.7	16.5	12	14.5	14.3	16.2	12	14.3	164.8	
A.D.	6.0	7.2	5.2	3.5	5.7	5.0	4.7	5.5	2.5	4.7	38.8	
Errors			570					419				
%Acc								86.3			83.84	

Rate 5 Met. 240

Trials	1	2	3	4	5	6	7	8	9	10	sum	dev.
Errors—touches												
Mz.	52	46	51	48	46	53	49	45	41	37	468	41.2
Ad	64	58	57	56	59	51	51	62	54	63	575	65.8
Dw	50	49	35	34	45	36	36	42	53	40	420	89.2
Wn	50	46	53	52	49	42	37	42	38	42	451	58.2
Ant	70	68	49	39	65	59	62	67	55	56	590	80.8
Sc	66	63	63	43	55	40	64	65	52	40	551	41.8
Total	352	330	308	272	319	221	299	323	293	278	3055	377.0
Av.	58.7	55	51.5	45.3	53.2	47	49.8	54	49	46.3	509.2	
A.D.	8.0	80	6.3	6.7	6.5	7.5	9.2	10.8	6.2	7.3	62.8	
Errors			1581					1474				
%Acc								51.8			50.1	

consequently it was deemed best to treat all errors as equal.

It is not necessary to repeat what was said in a previous connection concerning the measurement of changes in accuracy by number of errors made at different rates—nor to state again that although the tracing at Rate 1 has 1/5 as many touches as at Rate 3, it is not 5 times as accurate, but rather 1.09 times. Diagram 13 shows the corresponding changes in the two variables with increase in rate. As the speed of tracing increases 60%, the accuracy decreases 3.7% (measured from Rate 1), and when the speed increases 100%, the accuracy decreases 1.1%; an increase of 167% in speed results in a loss in accuracy of 17.6%, and at Rate 5, with an increase in speed of 300%, there is a "drop" in accuracy of 59%. In this experiment the decrease in accuracy seems to be slightly more rapid than in the thrusting experiment, though the accuracy curves for both experiments are very close together.

Practice was clearly evident at all rates, and largely concentrated in the early trials. Diagram 14 shows the changes from trial to trial for each rate, and with the exception of Rate 1 and Rate 5, practice seems to have spent itself by the time the 5th or 6th trial is reached. In the case of Rate 1, accuracy remains at nearly the same level throughout, except for a slight downward trend at trial 3; while in Rate 5, practice making for accuracy, seems about balanced by speed or interference making for inaccuracy. The dotted line (Diagram 14) drawn in on the curve for Rate 5 represents what the level of accuracy for this rate would probably be, were the trials continued long enough for these factors to equiliberate each other.

Interference has been mentioned as a factor which along with speed made for inaccuracy. It will be remembered that, in order to avoid a concentration of the practice effect at one rate, successive sheets were traced at different rates following a regular order. This plan necessitated a shift from rate to rate, and caused a majority of touches to appear in the first section of the maze, due to faulty adjustment to the changed rhythm. This interference grew gradually less as the experiment continued, and as the subject became habituated to the different rhythms. In spite of this fact, however, if we make due allowance for the interference factor, it is very true that the procedure used in the present experi-

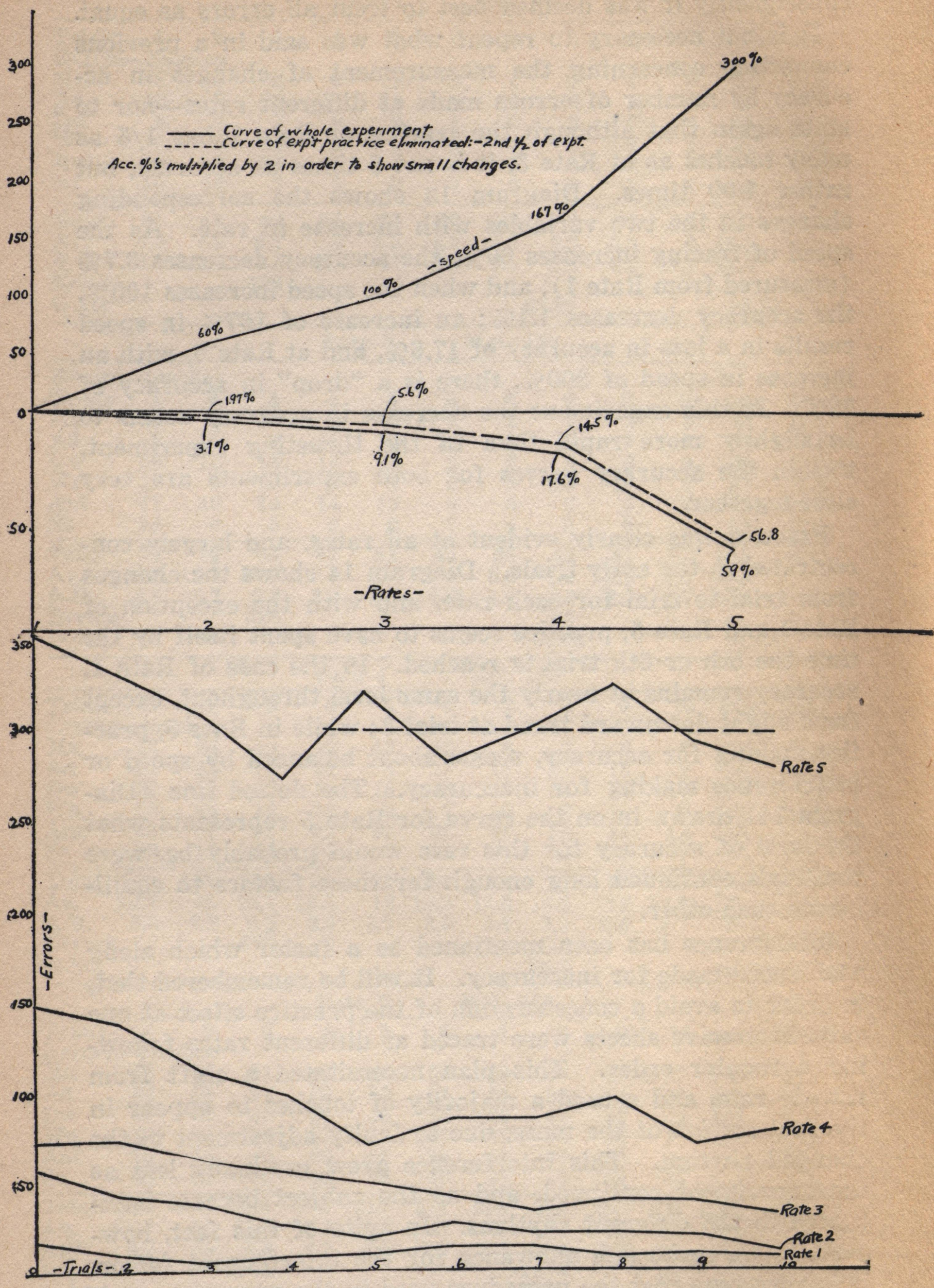


Diagram 13.—Showing the changes in the accuracy of tracing corresponding to the changes in the rate. Both speed and accuracy measured from Rate 1.

Diagram 14.—Practice curves for Rates 1, 2, 3, 4, 5,—showing changes for each trial from 1-10. Errors measured in "touches."

ment tends to make the accuracy records for any given rate lower than they would be had all the sheets at one rate been traced successively. This could not be done in this experiment, since, with any other procedure than the one used, the different rates would not have been comparable—and results would have been vitiated by a massing of practice, the avoidance of which was absolutely necessary for a fair comparison.

By grouping the trials from 6 to 10 together, I have calculated what the loss in accuracy at each rate would be, with practice eliminated. These average are represented in Diagram 13 by the dotted line, and show, except at Rate 1, an increase of between 1½%-3% in accuracy over the corresponding records for the whole experiment.

The question of an optimum rate for tracing brings up the same problem raised by the thrusting experiment. If accuracy alone is considered Rate 1 is clearly optimal. But if Speed and Accuracy both are taken into account, Rate 2, Rate 3, or even Rate 4, have claims over Rate 1. Of course Rate 5, the errors at which are more than 50% of the total number of movements, cannot be considered. Expressed in terms of increase in accuracy, Rate 1 is only 1.02 times as accurate as Rate 2; 1.057 times as accurate as Rate 3; and 1.17 times as accurate as Rate 4.

The variability of the six subjects as measured by the AD is greatest at Rate 5. Here there is an average of 509.2 touches with an AD from this average of 62.8. After Rate 5, the subjects tend to "spread out" most at Rate 4 and Rate 2 in order given, "bunching" together more closely at Rates 1 and 3. The explanation of the variability suggested in the thrusting experiment was that subjects tend to be more nearly alike at the very slow rates or the very fast rates, due to the ease of the former and the difficulty of the latter; while the intermediate rates really test the subject's ability in co-ordination, and hence are more "spread out." This same explanation cannot be carried over to the tracing experiment, without considerable modification. From Rate 1 to Rate 2, there is an increase in the variability but there is a decrease at Rate 3, due largely to Dw's large, and Sc's small increase in error. At Rate 4 there is an increased "spread" which continues over into Rate 5. The wide range at Rate 5, in contrast with the decrease in variability at the same rate in the thrusting experiment, is very probably due to the fact that,

the movement being shorter in tracing, Rate 5 is not as fast in tracing as in thrusting. A higher rate of speed might reduce the range among individuals. Practice, too, as a result of the thrusting experiment (tracing came second) might tend to carry over the individual differences from the former experiment.

The statement has been made that the functions involved in tracing and thrusting are very similar, and the inference was made that, for this reason, we should expect the same man's records in the two experiments to correspond closely. In the following table the relative positions of each subject in the two tests have been compared for each rate. (For the thrusting experiments at Rates 1 and 2, the second series have been used.)

	Rate 1		Rate 2		Rate 3		Rate 4		Rate 5		Final-Rel. Pos.	
	Th.	Tr.	Th.	Tr.	Th.	Tr.	Th.	Tr.	Th.	Tr.	Th.	Tr.
MZ.	3	4	1	1	3	2	3	1	5	3	3	2
AD.	6	5	6	5	5	4	5	4	6	5	6	5
DW.	4	2	4	2	4	6	6	5	3	1	4	4
WN.	1	1	2.5	3	1	3	1	2	1	2	1	1
ANT.	5	6	5	6	6	5	4	6	4	6	5	6
SC.	2	3	2.5	4	2	1	2	3	2	4	2	3

The correlation between the two tests is very high. Wn. in first in both tracing and thrusting; Mz, is second in tracing and third in thrusting; Sc. is third in tracing and second in thrusting; Dw. is in fourth place in both experiments; while Ad. and Ant. occupy the 6th and 5th places in thrusting, and the 5th and 6th places in tracing, respectively.

These results would surely seem to justify the inference that the functions involved in the two sorts of movement are much the same. Those factors which make for accuracy in the one experiment, determine to a large extent accuracy in the other also.

CONCLUSION

1.—In general, Speed and Accuracy are inversely related in maze tracing though the loss in accuracy is not comparable to the increase in speed.

2.—Practice, except at Rate 5, is largely concentrated in the first half of the trials at each rate. In the latter half, practice effect is very slight, or altogether negligible.

3.—When the speed of the movement is of importance, the optmum rate will probably shift from Rate 1 to Rate 2 or 3.

4.—Individual Subjects hold their positions (relative) from one rate to another with a high degree of consistency. Correlation between skill in thrusting and skill in tracing is very high, indicating clearly that the same essential factors are involved in the two functions.

5.—Some indviduals have better muscular control, are less easily confused, have greater perseverance, and more patience than others. Individual differences are largely due to these factors.

SECTION IV

RECAPITULATION AND SUMMARY

The primary object of this paper, as stated in the Introduction, was to answer certain questions having to do with the relation of speed to accuracy. These questions have all been answered, as fully as the experimental results seemed to justify under the separate experiments, and only a brief summary of the facts already given is here attempted. Each question is considered separately, in the same order in which it comes in the Introduction.

1.—Will accuracy fall off regularly as the speed increases, or is there an "optimal" point at which the accuracy is greater than at lower or higher rates? The experiments on lifted weights, linear magnitudes, and handwriting specimens have shown that accuracy is not highest when the speed or the rate is slowest, but that accuracy tends to increase gradually from the slowest rate used, 4″, to a 2″ rate, after which it falls off regularly, the loss becoming more rapid as the speed increases to 1″, and ½″. This indicates an optimal interval close to 2″ for all three experiments, a period at which the factors involved in judgment are at a point of maximal clearness. A lengthening or a shortening of this optimal time, through the introduction of irrelevant factors, or the failure of the factors involved in judgment to mature, results in either case in a loss of accuracy. In simple motor co-ordination, the speed-accuracy relation is inverse, thought not proportional. Accuracy decreases as the speed of the movement increases, though with practice the thrusting movement was made just as accurately in 5/8″, metronome at 96, as in 1″, metronome at 60.

2.—How do increases in speed affect accuracy? The loss in accuracy with increased speed is relatively very slight. In the experiment on lifted weights, the accuracy for all six observers ranged from 76.3% at a 4″ lifting rate, to 80.1% at 2″, and fell to 70.9% at the 1″rate. Thus a decrease of 75% in time interval, or an increase of 300% in the speed of lift, caused a change in accuracy of only 10%. In comparing lines, the accuracy at the 4″ exposure interval was 66.73%; this increased to 70.28% at 2″ interval, and dropped to

62.64% at ½″ interval. Again, an increase of 700% in the rate with which the cards were exposed, resulted in a change of about 8% in the accuracy. In comparing specimens of handwriting, a change of 300% in speed was paralleled by a total change of 6.3% in accuracy. With the co-ordination experiments, the changes in accuracy were much greater. As the speed of thrusting increased from 1″ to ¼″, 300%, the accuracy fell from 100% of hits to 53.5% of hits; and in maze tracing, with the same increase in rate the accuracy fell from 97.8% to 40.1%. In both of these experiments the accuracy fell off rather slowly at first increasing by leaps as the rate became more rapid.

3.—Do speed and accuracy have essentially the same relation in the perception of differences as in simple co-ordinated movements, or does the accuracy behave differently in the two cases? At first glance it would seem from the above discussion that accuracy does not vary alike in the two cases. It is doubtful, however, if we can fairly compare the speed-accuracy relationship in situations which are as different as those in the movement and perception experiments. The actual increase in accuracy as the time for perception of differences is shortened, up to a certain point, and the subsequent loss in accuracy after this point has been passed, has been explained as due to the fact that an optimal time or period—and no more—is needed for the factors involved in the judgment, visual, kinaesthetic etc.— to become maximally clear; or for the memory or set, and in the case of lifted weights, motor "Einstellung," to "carry over" from one impression to the next. In the motor co-ordination experiments, on the contrary, no comparison, memory, or judgment were required. The subject simply made the movement at designated time intervals, which, after practice became fairly automatic, although the angular character of the thrusting and the difference in direction of the tracing prevented a "momentum of uniformity"[89] from being set up. Accuracy is, therefore, largely dependent upon dexterity, skillful co-ordination of arm, hand, and eye. At the slow rates the errors are due mostly to carelessness; as the rate increases the accuracy decreases rapidly until as the "physiological limit" is reached, the time becomes so short that the neouro-muscular mechanism cannot function with any precision in the time allowed.

If we take the two groups of experiments, the perception—of difference group as rate increase from the 2″ point of maximal accuracy, and the two movement experiments as rate increases the 1″ point of 100% accuracy, we find that in both cases there is an inverse relation of speed and accuracy, though the decrease in accuracy is much greater in the movement experiments. This relatively large loss in accuracy is partly due to the fact that the times for the movements were actually much faster than the times allowed for perceiving differences. For example, the slowest thrusting or tracing time was 1″, 4 times as fast as the slowest rate in the perception experiments, and the ratio holds for the other rates. Accuracy behaves alike in the two cases, in that after a certain point, any increase in speed causes a "drop" in accuracy; but before this point is reached, increase in rates affect the observer differently, for reasons already indicated.

4.—Does the same individual hold his relative position in the different situations,—is he fast and accurate, slow and accurate, etc., or can individuals be so classified? In attempting to get at the relative standing of an individual in the 5 experiments, it has been realized that although a large number of trials were made at each rate in every experiment, that there were only six observers, and that, therefore, conclusions as to relative position are conditioned by the size of this group. In the following table the "best rate,"—the rate at which accuracy was highest,—is given for each observer, the % of accuracy, and the individual's standing in the group, considering the whole experiment. The two movement experiments have been considered together, as they gave results so closely correlated, that it did not seem worth while to consider them separately.

At first glance the differences between the records of the observer,—the range from highest to lowest,—are so small, that with one or two exceptions, we might well say that one observer was about as good as another in perceiving small differences, whether of weights, lines, or specimens of handwriting. Especially in the line experiment, the differences are so small,—only 2.9% between the highest and lowest record, that it is impossible to say any observer was definitely "best" at any rate. A further examination of the table, however,

[88]Woodworth: Accuracy of Voluntary Movement, Psy. Rev. Mon. Sup. *13*, p. 27-62.

TABLE XX

Obs.	"Best Rate"	Rel. Pos. in Exp.	%Accuracy.
		Weight Lifting	
Mz	3	4	81.0
Ad	1	6	74.7
Dw	3	3	81.7
Wn	3	1	84.0
Ant	1	5	80.3
Sc	2	2	82.7
		Lines	
Obs.			
Mz	3	1	73.7
Ad	3	4.5	70.8
Dw	1	3	72.1
Wn	2	2	72.9
Ant	2	4.5	70.8
Sc	5	6	70.4
		Handwriting	
Obs.			
Mz	3	1	77.81
Ad	2	4	72.95
Dw	3	3	73.14
Wn	3	5	69.90
Ant	2	2	74.38
Sc	–	–	–
		Coordination Exper.	
Obs.			
Mz	1	4.0	
Ad	1	5.5	
Dw	1	3	
Wn	1	1	
Ant	1	5.5	
Sc	1	2.0	

reveals certain definite tendencies. Mz, for example, ranks first in comparing lines and in perceiving differences in handwriting, but he drops to 4th place in the perception of differences in weight and in co-ordination. It might be expected, that skill in weight lifting would be correlated with skill in thrusting and tracing, since the former partly, and the latter almost wholly depend on muscular precision, and kinaesthetic factors. Further evidence in favor of this inference is seen in Wn's and Sc's records. These observers rank first and second respectively in the accuracy of weight comparison, and in co-ordination, while Ad and Ant rank last and next to the last. On the other hand, Wn is in 5th place in comparing handwriting specimens, and Ant is in 2nd place. Also, in estimating linear differences, Wn is 2nd and Sc is 6th, though these differences in records are largely to be discounted because of the slight range in accuracy in this experiment. Ad ranks uniformly low,—5th or 6th place—in all the experiments.

It seems that the conclusion is justified, therefore, that an observer holds his relative position in those experiments in which the functions involved are closely related: an observer who is relatively accurate in perceiving differences in weights, will also be accurate in co-ordinating simple hand and arm movements,—and the reverse is also true. There seems to be little relation between ability to perceive weight differences, or differences between linear magnitudes, or specimens of handwriting. Observers accurate in the one experiment may or may not be accurate in the other two.

A word should be said in regard to the rates used. They were entirely the result of experiment and were not predetermined. No slower rate than 4″ was deemed necessary because accuracy always increased from this rate, while Rate 5, 1″, except in the Line Experiment showed an accuracy loss sufficiently large to make further reductions in exposure time,—in order to show the general trend—unnecessary.